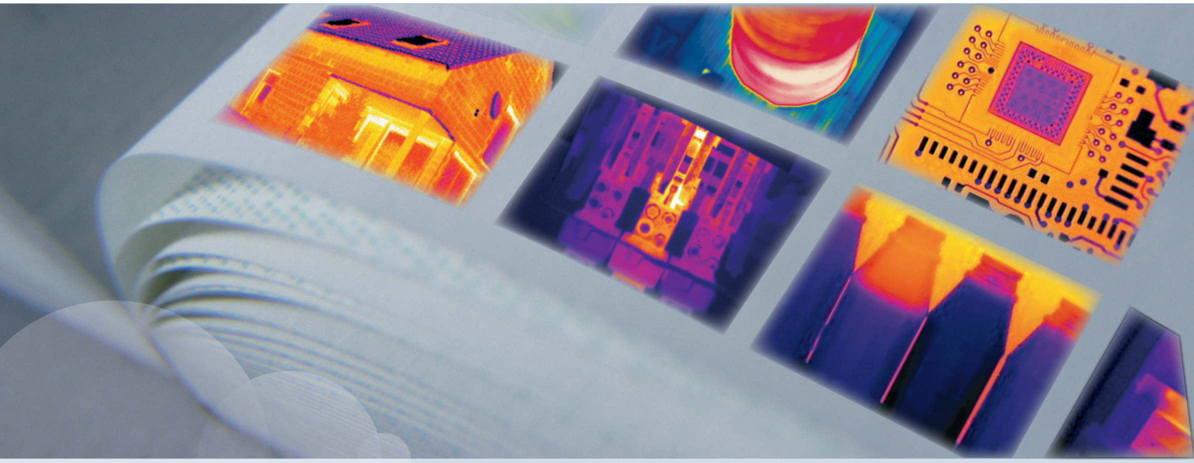
User’s manual



FLIR A3xx f series
FLIR A3xx pt series

Publ. No.	T559743
Revision	a601
Language	English (EN)
Issue date	April 26, 2012

User’s manual

Publ. No. T559743 Rev. a601 – ENGLISH (EN) – April 26, 2012

Legal disclaimer

All products manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of one (1) year from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction.

Uncooled handheld infrared cameras manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of two (2) years from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction, and provided that the camera has been registered within 60 days of original purchase.

Detectors for uncooled handheld infrared cameras manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of ten (10) years from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction, and provided that the camera has been registered within 60 days of original purchase.

Products which are not manufactured by FLIR Systems but included in systems delivered by FLIR Systems to the original purchaser, carry the warranty, if any, of the particular supplier only. FLIR Systems has no responsibility whatsoever for such products.

The warranty extends only to the original purchaser and is not transferable. It is not applicable to any product which has been subjected to misuse, neglect, accident or abnormal conditions of operation. Expendable parts are excluded from the warranty.

In the case of a defect in a product covered by this warranty the product must not be further used in order to prevent additional damage. The purchaser shall promptly report any defect to FLIR Systems or this warranty will not apply.

FLIR Systems will, at its option, repair or replace any such defective product free of charge if, upon inspection, it proves to be defective in material or workmanship and provided that it is returned to FLIR Systems within the said one-year period.

FLIR Systems has no other obligation or liability for defects than those set forth above.

No other warranty is expressed or implied. FLIR Systems specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

FLIR Systems shall not be liable for any direct, indirect, special, incidental or consequential loss or damage, whether based on contract, tort or any other legal theory.

This warranty shall be governed by Swedish law.

Any dispute, controversy or claim arising out of or in connection with this warranty, shall be finally settled by arbitration in accordance with the Rules of the Arbitration Institute of the Stockholm Chamber of Commerce. The place of arbitration shall be Stockholm. The language to be used in the arbitral proceedings shall be English.

Copyright

Quality assurance

The Quality Management System under which these products are developed and manufactured has been certified in accordance with the ISO 9001 standard.

FLIR Systems is committed to a policy of continuous development; therefore we reserve the right to make changes and improvements on any of the products described in this manual without prior notice.

Patents

One or several of the following patents or design patents apply to the products and/or features described in this manual:

0002258-2; 000279476-0001; 000439161; 000499579-0001; 000653423; 000726344; 000859020; 000889290; 001106306-0001; 001707738; 001707746; 001707787; 001776519; 0101577-5; 0102150-0; 0200629-4; 0300911-5; 0302837-0; 1144833; 1182246; 1182620; 1188086; 1285345; 1287138; 1299699; 1325808; 1336775; 1365299; 1402918; 1404291; 1678485; 1732314; 200530018812.0; 200830143636.7; 2106017; 235308; 3006596; 3006597; 466540; 483782; 484155; 518836; 60004227.8; 60122153.2; 602004011681.5-08; 6707044; 68657; 7034300; 7110035; 7154093; 7157705; 7237946; 7312822; 7332716; 7336823; 7544944; 75530; 7667198; 7809258; 7826736; D540838; D549758; D579475; D584755; D599,392; DI6702302-9; DI6703574-4; DI6803572-1; DI6803853-4; DI6903617-9; DM/057692; DM/061609; Registration Number; ZL00809178.1; ZL01823221.3; ZL01823226.4; ZL02331553.9; ZL02331554.7; ZL200480034894.0; ZL200530120994.2; ZL200630130114.4; ZL200730151141.4; ZL200730339504.7; ZL200830128581.2; ZL200930190061.9

Table of contents

1 Warnings & Cautions

WARNING

- (Applies only to Class A digital devices.) This equipment generates, uses, and can radiate radio frequency energy and if not installed and used in accordance with the instruction manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference.
- (Applies only to Class B digital devices.) This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:
  - Reorient or relocate the receiving antenna.
  - Increase the separation between the equipment and receiver.
  - Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
  - Consult the dealer or an experienced radio/TV technician for help.
- (Applies only to digital devices subject to 15.19/RSS-210.) **NOTICE**: This device complies with Part 15 of the FCC Rules and with RSS-210 of Industry Canada. Operation is subject to the following two conditions:
  1. this device may not cause harmful interference, and
  2. this device must accept any interference received, including interference that may cause undesired operation.
- (Applies only to digital devices subject to 15.21.) **NOTICE**: Changes or modifications made to this equipment not expressly approved by (manufacturer name) may void the FCC authorization to operate this equipment.
- (Applies only to digital devices subject to 2.1091/2.1093/OET Bulletin 65.) **Radiofrequency radiation exposure Information**: The radiated output power of the device is far below the FCC radio frequency exposure limits. Nevertheless, the device shall be used in such a manner that the potential for human contact during normal operation is minimized.
- (Applies only to cameras with laser pointer:) Do not look directly into the laser beam. The laser beam can cause eye irritation.
- Applies only to cameras with battery:
  - Do not disassemble or do a modification to the battery. The battery contains safety and protection devices which, if they become damaged, can cause the battery to become hot, or cause an explosion or an ignition.

  - If there is a leak from the battery and the fluid gets into your eyes, do not rub your eyes. Flush well with water and immediately get medical care. The battery fluid can cause injury to your eyes if you do not do this.
  - Do not continue to charge the battery if it does not become charged in the specified charging time. If you continue to charge the battery, it can become hot and cause an explosion or ignition.
  - Only use the correct equipment to discharge the battery. If you do not use the correct equipment, you can decrease the performance or the life cycle of the battery. If you do not use the correct equipment, an incorrect flow of current to the battery can occur. This can cause the battery to become hot, or cause an explosion and injury to persons.

- Make sure that you read all applicable MSDS (Material Safety Data Sheets) and warning labels on containers before you use a liquid: the liquids can be dangerous.
- If mounting the A3xx pt/A3xx f series camera on a pole, tower or any elevated location, use industry standard safe practices to avoid injuries.

CAUTION

- Do not point the infrared camera (with or without the lens cover) at intensive energy sources, for example devices that emit laser radiation, or the sun. This can have an unwanted effect on the accuracy of the camera. It can also cause damage to the detector in the camera.
- Do not use the camera in a temperature higher than +50°C (+122°F), unless specified otherwise in the user documentation. High temperatures can cause damage to the camera.
- (Applies only to cameras with laser pointer:) Protect the laser pointer with the protective cap when you do not operate the laser pointer.
- Applies only to cameras with battery:
  - Do not attach the batteries directly to a car's cigarette lighter socket, unless a specific adapter for connecting the batteries to a cigarette lighter socket is provided by FLIR Systems.
  - Do not connect the positive terminal and the negative terminal of the battery to each other with a metal object (such as wire).
  - Do not get water or salt water on the battery, or permit the battery to get wet.
  - Do not make holes in the battery with objects. Do not hit the battery with a hammer. Do not step on the battery, or apply strong impacts or shocks to it.
  - Do not put the batteries in or near a fire, or into direct sunlight. When the battery becomes hot, the built-in safety equipment becomes energized and can stop the battery charging process. If the battery becomes hot, damage can occur to the safety equipment and this can cause more heat, damage or ignition of the battery.
  - Do not put the battery on a fire or increase the temperature of the battery with heat.
  - Do not put the battery on or near fires, stoves, or other high-temperature locations.
  - Do not solder directly onto the battery.
  - Do not use the battery if, when you use, charge, or store the battery, there is an unusual smell from the battery, the battery feels hot, changes color, changes shape, or is in an unusual condition. Contact your sales office if one or more of these problems occurs.
  - Only use a specified battery charger when you charge the battery.

- The temperature range through which you can charge the battery is ±0°C to +45°C (+32°F to +113°F), unless specified otherwise in the user documentation. If you charge the battery at temperatures out of this range, it can cause the battery to become hot or to break. It can also decrease the performance or the life cycle of the battery.
- The temperature range through which you can discharge the battery is −15°C to +50°C (+5°F to +122°F), unless specified otherwise in the user documentation. Use of the battery out of this temperature range can decrease the performance or the life cycle of the battery.
- When the battery is worn, apply insulation to the terminals with adhesive tape or similar materials before you discard it.
- Remove any water or moisture on the battery before you install it.

- Do not apply solvents or similar liquids to the camera, the cables, or other items. This can cause damage.
- Be careful when you clean the infrared lens. The lens has a delicate anti-reflective coating.
- Do not clean the infrared lens too vigorously. This can damage the anti-reflective coating.
- In furnace and other high-temperature applications, you must mount a heatshield on the camera. Using the camera in furnace and other high-temperature applications without a heatshield can cause damage to the camera.
- (Applies only to cameras with an automatic shutter that can be disabled.) Do not disable the automatic shutter in the camera for a prolonged time period (typically max. 30 minutes). Disabling the shutter for a longer time period may harm, or irreparably damage, the detector.
- The encapsulation rating is valid only when all openings on the camera are sealed with their designated covers, hatches, or caps. This includes, but is not limited to, compartments for data storage, batteries, and connectors.
- (Applies only to FLIR A3xx f/A3xx pt series cameras.)
    - Except as described in this manual, do not open the FLIR A3xx pt/A3xx f series camera for any reason. Disassembly of the camera (including removal of the cover) can cause permanent damage and will void the warranty.
    - Do not to leave fingerprints on the FLIR A3xx pt/A3xx f series camera's infrared optics.
    - The FLIR A3xx pt/A3xx f series camera requires a power supply of 24 VDC. Operating the camera outside of the specified input voltage range or the specified operating temperature range can cause permanent damage.
    - When lifting the FLIR A3xx pt series camera use the camera body and base, not the tubes.
- (Applies only to FLIR GF309 cameras.) **CAUTION:** The exceptionally wide temperature range of the FLIR GF309 infrared camera is designed for performing highly accurate electrical and mechanical inspections and can also "see through flames" for inspecting gas-fired furnaces, chemical heaters and coal-fired boilers. IN ORDER TO DERIVE ACCURATE TEMPERATURE MEASUREMENTS IN THESE ENVIRONMENTS THE GF309 OPERATOR MUST HAVE A STRONG UNDERSTANDING OF RADIOMETRIC FUNDAMENTALS AS WELL AS THE PRODUCTS AND CONDITIONS OF COMBUSTION THAT IMPACT REMOTE TEMPERATURE MEASUREMENT. The Infrared Training Center (itc) offers a wide range of world class infrared

training for thermography professionals including GF309 operators. For more information about obtaining the training and certification you require, contact your FLIR sales representative or itc at www.infraredtraining.com.

2 Notice to user

Typographical conventions

This manual uses the following typographical conventions:

- **Semibold** is used for menu names, menu commands and labels, and buttons in dialog boxes.
- *Italic* is used for important information.
- `Monospace` is used for code samples.
- UPPER CASE is used for names on keys and buttons.

User-to-user forums

Exchange ideas, problems, and infrared solutions with fellow thermographers around the world in our user-to-user forums. To go to the forums, visit:

http://www.infraredtraining.com/community/boards/

Calibration

(This notice only applies to cameras with measurement capabilities.)

We recommend that you send in the camera for calibration once a year. Contact your local sales office for instructions on where to send the camera.

Accuracy

(This notice only applies to cameras with measurement capabilities.)

For very accurate results, we recommend that you wait 5 minutes after you have started the camera before measuring a temperature.

For cameras where the detector is cooled by a mechanical cooler, this time period excludes the time it takes to cool down the detector.

Disposal of electronic waste

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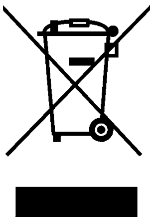

As with most electronic products, this equipment must be disposed of in an environmentally friendly way, and in accordance with existing regulations for electronic waste.

Please contact your FLIR Systems representative for more details.

Training

To read about infrared training, visit:

- http://www.infraredtraining.com
- http://www.irtraining.com
- http://www.irtraining.eu

Additional license information

This license permits the user to install and use the software on any compatible computer, provided the software is used on a maximum of two (2) computers at the same time (for example, one laptop computer for on-site data acquisition, and one desktop computer for analysis in the office).

One (1) back-up copy of the software may also be made for archive purposes.

3 Customer help

General

For customer help, visit:

http://support.flir.com

Submitting a question

To submit a question to the customer help team, you must be a registered user. It only takes a few minutes to register online. If you only want to search the knowledge-base for existing questions and answers, you do not need to be a registered user.

When you want to submit a question, make sure that you have the following information to hand:

- The camera model
- The camera serial number
- The communication protocol, or method, between the camera and your PC (for example, HDMI, Ethernet, USB™, or FireWire™)
- Operating system on your PC
- Microsoft® Office version
- Full name, publication number, and revision number of the manual

Downloads

On the customer help site you can also download the following:

- Firmware updates for your infrared camera
- Program updates for your PC software
- User documentation
- Application stories
- Technical publications

4 Documentation updates

General

Our manuals are updated several times per year, and we also issue product-critical notifications of changes on a regular basis.

To access the latest manuals and notifications, go to the Download tab at:

http://support.flir.com

It only takes a few minutes to register online. In the download area you will also find the latest releases of manuals for our other products, as well as manuals for our historical and obsolete products.

5 Important note about this manual

General

FLIR Systems issues generic manuals that cover several cameras within a model line.

This means that this manual may contain descriptions and explanations that do not apply to your particular camera model.

NOTE

FLIR Systems reserves the right to discontinue models, software, parts or accessories, and other items, or to change specifications and/or functionality at any time without prior notice.

6 Introduction

6.1 FLIR A3xx f series

T639344;a1

Figure 6.1 FLIR A3xx f series

The main purpose of FLIR A3xx f series is, by adding the housing, to increase the environmental specification of the standard FLIR A3xx series to IP 66 without affecting any of the features available in the camera itself.

The built-in FLIR A3xx f series camera offers an affordable and accurate temperature measurement solution for anyone who needs to solve problems that do not call for the highest speed or reaction and who uses a PC. Due to to its composite video output, it is also an excellent choice for thermal image automation applications, where you can utilize its unique properties such as looking through steam.

Key features:

- MPEG-4 streaming
- PoE (Power over Ethernet)
- Built-in web server
- General purpose I/O
- 100 Mbps Ethernet (100 m cable, wireless, fiber, etc.)
- Synchronization through SNTP
- Composite video output
- Multi-camera utility software: FLIR IP Config and FLIR IR Monitor included
- Open and well-described TCP/IP protocol for control and set-up

- 16-bit 320 × 240 images @ 3 Hz, radiometric
- Multi-camera software: FLIR Sensor Manager allows users to manage and control a FLIR A3xx f series camera in a TCP/IP network.

Typical applications:

- Fire prevention, critical vessel monitoring, and power utility asset management
- Volume-oriented industrial control (multi-camera installation is possible)

6.2 FLIR A3xx pt series

T639343;a1

Figure 6.2 FLIR A3xx pt series

The FLIR A3xx pt series offers an affordable solution for anyone who needs to solve problems that need built in “smartness” such as analysis and alarm functionality. The FLIR A3xx pt series has all the necessary features and functions to build distributed single- or multi-camera solutions to cover large areas to monitor such as in coal pile monitoring, sub-station monitoring utilizing standard Ethernet hardware and software protocols.

The FLIR A3xx pt series precision pan/tilt mechanism gives operators accurate pointing control while providing fully programmable scan patterns, radar slew-to-cue, and slew-to-alarm functionality.

Multi-sensor configurations also include a day/night 36× zoom color CCD camera on the same pan/tilt package.

Key features:

- Built-in extensive analysis functionality.

- Extensive alarm functionality, as a function of analysis and more.
- H.264, MPEG-4 and MJPEG streaming.
- Built-in web server.
- 100 Mbps Ethernet (100 m cable, wireless, fiber, etc.).
- Composite video output.
- Precise pan/tilt mechanism.
- Daylight camera.
- IP66
- IP control, the FLIR A3xx pt series can be integrated in any existing TCP/IP network and controlled over a PC.
- Serial control interface, use Pelco D or Bosch commands over RS-232, RS-422 or RS-485 to a remotely control the FLIR A3xx pt series.
- Multi-camera software: FLIR Sensor Manager allows users to manage and control a FLIR A3xx pt series camera in a TCP/IP network.

7 Parts lists

7.1 *Packaging contents (FLIR A3xx f series)*

- Cardboard box
- Infrared camera with lens and environmental housing
- Calibration certificate
- Downloads brochure
- FLIR Sensor Manager CD-ROM
- Lens cap
- Printed Getting Started Guide
- Printed Important Information Guide
- Service & training brochure
- Small accessories kit
- User documentation CD-ROM
- FLIR Tools & Utilities CD-ROM
- Registration card

NOTE: FLIR Systems reserves the right to discontinue models, parts or accessories, and other items, or to change specifications at any time without prior notice.

7.2 *Packaging contents (FLIR A3xx pt series)*

- Cardboard box
- Pan & tilt head with infrared camera, including lens and visual camera
- Calibration certificate
- Downloads brochure
- FLIR Sensor Manager CD-ROM
- Lens cap
- Printed Getting Started Guide
- Printed Important Information Guide
- Service & training brochure
- Small accessories kit
- User documentation CD-ROM
- FLIR Tools & Utilities CD-ROM
- Registration card

NOTE: FLIR Systems reserves the right to discontinue models, parts or accessories, and other items, or to change specifications at any time without prior notice.

8 Installation (FLIR A3xx f series)

8.1 Installation overview

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Figure 8.1 FLIR A3xx f series

The FLIR A3xx f series camera is an infrared thermal imaging camera intended for outdoor applications, and can be installed in a fixed location or on a pan/tilt mechanism.

The FLIR A3xx f series camera is intended to be mounted on a medium-duty fixed pedestal mount or wall mount commonly used in the CCTV industry. Cables will exit from the back of the camera housing. The mount must support up to 30 lbs. (15 kg).

The FLIR A3xx f series is both an analog camera and an IP camera. The video from the camera can be viewed over a traditional analog video network, and it can be viewed by streaming it over an IP network using MPEG-4 encoding. Analog video will require a connection to a video monitor or an analog matrix/switch. The IP video will require a connection to an Ethernet network switch, and a computer with the appropriate software for viewing the video.

The camera can be controlled through either serial or IP communications.

The camera operates on 12/24 VDC.

In order to access the electrical connections and install the cables, it is necessary to temporarily remove the back cover of the camera housing.

8.2 Installation components

The FLIR A3xx pt series camera includes these standard components:

- Cardboard box
- Infrared camera with lens and environmental housing

- Calibration certificate
- Downloads brochure
- FLIR Sensor Manager CD-ROM
- Lens cap
- Printed Getting Started Guide
- Printed Important Information Guide
- Service & training brochure
- Small accessories kit
- User documentation CD-ROM
- FLIR Tools & Utilities CD-ROM
- Registration card

The installer will need to supply the following items; the lengths are specific to the installation.

- Electrical wire, for system power; up to 100′ (3-conductor, shielded, gauge determined by cable length and supply voltage.
- Camera grounding strap
- Coaxial RG59U video cables (BNC connector at the camera end) for analog video
- Shielded Category 6 Ethernet cable for control and streaming video over an IP network; and also for software upgrades.
- Optional serial cable for serial communications
- Miscellaneous electrical hardware, connectors, and tools

8.3 Location considerations

The camera will require connections for power, communications (IP Ethernet, and/or RS232/RS422}, and video.

NOTE: Install all cameras with an easily accessible Ethernet connection to support future software upgrades.

Ensure that cable distances do not exceed the Referenced Standard specifications and adhere to all local and Industry Standards, Codes, and Best Practices.

8.4 Camera mounting

FLIR A3xx f series cameras must be mounted upright on top of the mounting surface, with the base below the camera. The unit shall not be hung upside down.

The FLIR A3xx f series camera can be secured to the mount with three to five 1/4″-20 bolts or studs as shown below.

Once the mounting location has been selected, verify both sides of the mounting surface are accessible.

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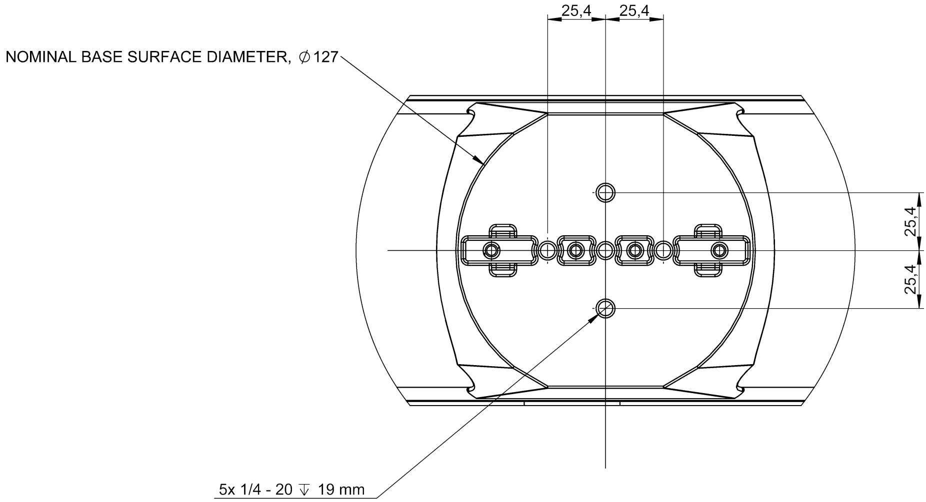

Figure 8.2 FLIR A3xx f series camera mounting (mm)

NOTE: If the camera is to be mounted on a pole or tower or other hard-to-reach location, connect and operate the camera as a bench test at ground level prior to mounting the camera in its final location.

Use a thread locking compound such as Loctite 242 or equivalent with all metal to metal threaded connections.

Using the template supplied with the camera as a guide, mark the location of the holes for mounting the camera.

If the template is printed, be sure it is printed to scale so the dimensions are correct.

Once the holes are drilled in the mounting surface, install three (3) to five (5) 1/4″-20 bolts or threaded studs into the base of the camera with thread-locking compound.

8.5 Prior to cutting/drilling holes

When selecting a mounting location for the FLIR A3xx f series camera, consider cable lengths and cable routing. Ensure the cables are long enough, given the proposed mounting locations and cable routing requirements, and route the cables before you install the components.

Use cables that have sufficient dimensions to ensure safety (for power cables) and adequate signal strength (for video and communications).

8.6 Back cover

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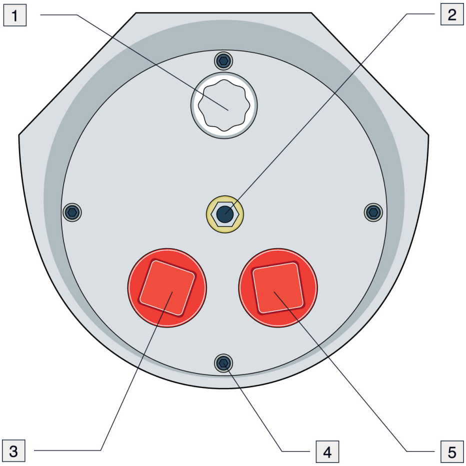
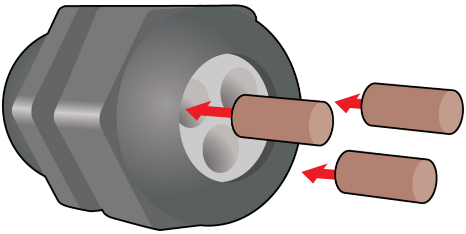


1	Breather valve
2	Ground lug
3	Shipping plug
4	Shipping plug
5	Mounting screw (×4)

T639385;a1



The FLIR A3xx f series camera comes with two 3/4″ NPT cable glands, each with a three hole gland seal insert. Cables may be between 0.23″ to 0.29″ OD. Typically up to five cables may be needed. Plugs are required for any insert hole(s) not being used.

If non-standard cable diameters are used, you may need to locate or fabricate the appropriate insert to fit the desired cable. FLIR Systems does not provide cable gland inserts other than what is supplied with the system.

NOTE: Insert the cables through the cable glands on the enclosure before terminating and connecting them. (In general, the terminated connectors will not fit through the cable gland.) If a terminated cable is required, you can make a clean and singular cut in the gland seal to install the cable into the gland seal.

Proper installation of cable sealing glands and use of appropriate elastomer inserts is critical to long term reliability. Cables enter the camera mount enclosure through liquid-tight compression glands. Be sure to insert the cables through the cable glands on the enclosure before terminating and connecting them (the connectors will not fit through the cable gland). Leave the gland nuts loosened until all cable installation has been completed. Inspect and install gland fittings in the back cover with suitable leak sealant and tighten to ensure water tight fittings. Teflon tape or pipe sealant (i.e. DuPont RectorSeal T™) are suitable for this purpose.

8.7 Removing the back cover

Use a 3 mm hex key to loosen the screws, exposing the connections at the back of the camera enclosure. There is a grounding wire connected between the case and the back cover as shown.

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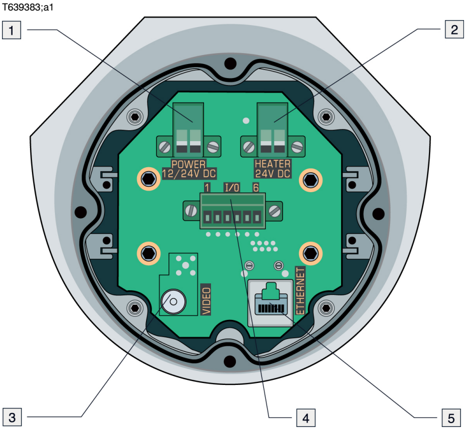


Figure 8.3 1: Camera power; 2: Camera heater; 3: Video; 4: I/O ports; 5: Ethernet

8.8 Connecting power

The camera itself does not have an on/off switch. Generally the FLIR A3xx f series camera will be connected to a circuit breaker and the circuit breaker will be used to apply or remove power to the camera. If power is supplied to it, the camera will be in one of two modes: Booting Up or Powered On.

The power cable supplied by the installer must use wires that are sufficient size gauge (16 AWG recommended) for the supply voltage and length of the cable run, to ensure adequate current carrying capacity. Always follow local building codes.

Ensure the camera is properly grounded. Typical to good grounding practices, the camera chassis ground should be provided using the lowest resistance path possible. FLIR Systems requires using a grounding strap anchored to the grounding lug on the back plate of the camera housing and connected to the nearest earth-grounding point.

NOTE: The terminal blocks for power connections will accept a maximum 16 AWG wire size.

8.9 Video connections

The analog video connection on the back of the camera is a BNC connector. The camera also provides an RCA video connector that can be used to temporarily monitor the video output, without disconnecting the BNC connection.

The video cable used should be rated as RG59U or better to ensure a quality video signal.

8.10 Ethernet connection

The cable gland seal is designed for use with Shielded Category 6 Ethernet cable.

9 Installation (FLIR A3xx pt series)

9.1 Installation overview

T639343;a1

Figure 9.1 FLIR A3xx pt series

The FLIR A3xx pt series camera is a multi-sensor camera system on a pan/tilt platform. Combinations of an infrared thermal imaging camera and a visible-light video camera are intended for outdoor installations.

The FLIR A3xx pt series camera is intended to be mounted on a medium-duty fixed pedestal mount or wall mount commonly used in the CCTV industry. Cables will exit from the back of the camera housing. The mount must support up to 45 lbs. (20 kg).

The FLIR A3xx pt series camera is both an analog and an IP camera. The video from the camera can be viewed over a traditional analog video network or it can be viewed by streaming it over an IP network using MPEG-4, M-JPEG and H.264 encoding. Analog video will require a connection to a video monitor or an analog matrix/switch. The IP video will require a connection to an Ethernet network switch, and a computer with the appropriate software for viewing the video stream.

The camera can be controlled through either serial or IP communications.

The camera operates on 12/24 VDC.

In order to access the electrical connections and install the cables, it is necessary to temporarily remove the back cover of the camera housing.

9.2 Installation components

The FLIR A3xx pt series camera includes these standard components:

- Cardboard box
- Pan & tilt head with infrared camera, including lens and visual camera

- Calibration certificate
- Downloads brochure
- FLIR Sensor Manager CD-ROM
- Lens cap
- Printed Getting Started Guide
- Printed Important Information Guide
- Service & training brochure
- Small accessories kit
- User documentation CD-ROM
- FLIR Tools & Utilities CD-ROM
- Registration card

The installer will need to supply the following items; the lengths are specific to the installation.

- Electrical wire, for system power
- Camera grounding strap
- Coaxial RG59U video cables (BNC connector at the camera end) for analog video
- Shielded Category 6 Ethernet cable for control and streaming video over an IP network; and also for software upgrades
- Optional serial cable for serial communications
- Miscellaneous electrical hardware, connectors, and tools

9.3 Location considerations

The camera will require connections for power, communications (IP Ethernet, and/or RS232/RS422), and video (two video connections may be required for analog video installations).

NOTE: Install all cameras with an easily accessible Ethernet connection to support future software upgrades.

Ensure that cable distances do not exceed the Referenced Standard specifications and adhere to all local and Industry Standards, Codes, and Best Practices.

T639358;a1

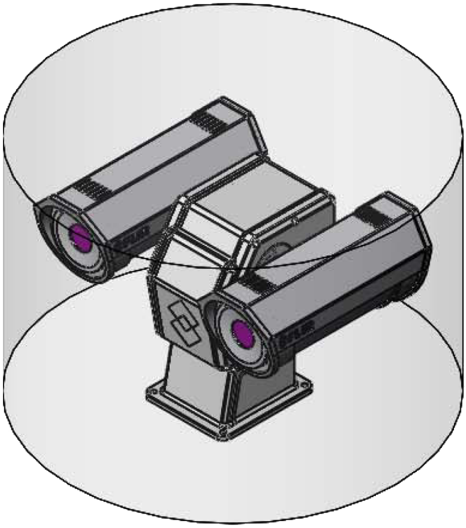


Figure 9.2 FLIR A3xx pt series exclusion zone. Height 480 mm (18.9″), diameter 740 mm (29.1″).

9.4 Camera mounting

FLIR A3xx pt series cameras must be mounted upright on top of the mounting surface, with the base below the camera. The unit should not be hung upside down.

The FLIR A3xx pt series camera can be secured to the mount with four 5/16″ or M8 bolts, as shown below.

Once the mounting location has been selected, verify both sides of the mounting surface are accessible.

T639345;a2

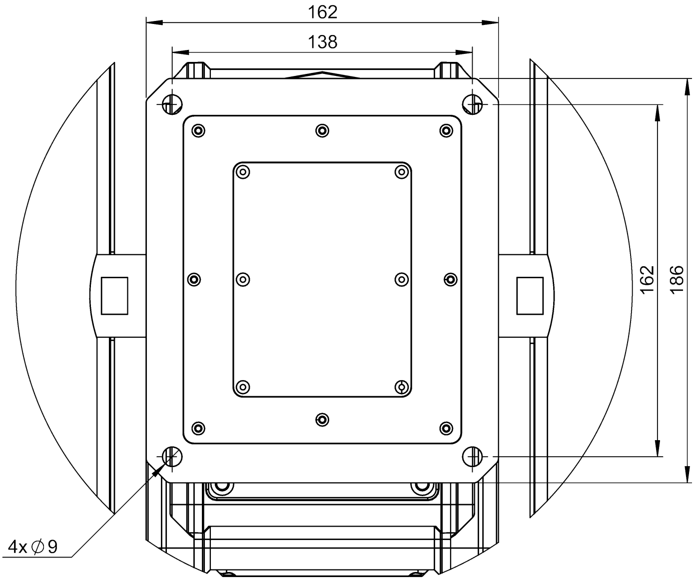


Figure 9.3 FLIR A3xx pt series camera mounting (mm)

NOTE: Connect and operate the camera as a bench test at ground level prior to mounting the camera in its final location.

Use a thread locking compound such as Loctite 242 or equivalent with all metal to metal threaded connections.

Using the template supplied with the camera as a guide, mark the location of the holes for mounting the camera. If the template is printed, be sure it is printed to scale so the dimensions are correct.

Once the holes are drilled in the mounting surface, install four (4) 5/16″ or M8 bolts through the base of the camera.

9.5 Prior to cutting/drilling holes

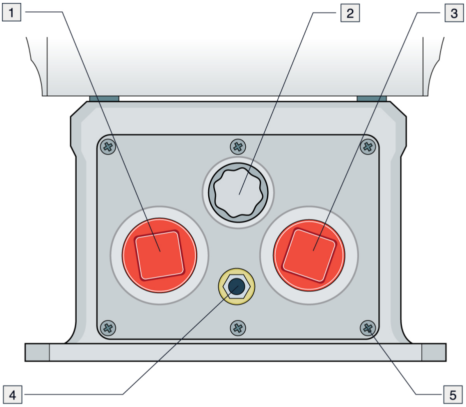
When selecting a mounting location for the FLIR A3xx pt series camera, consider cable lengths and cable routing. Ensure the cables are long enough given the proposed mounting locations and cable routing requirements.

Use cables that have sufficient dimensions to ensure safety (for power cables) and adequate signal strength (for video and communications).

9.6 Back cover

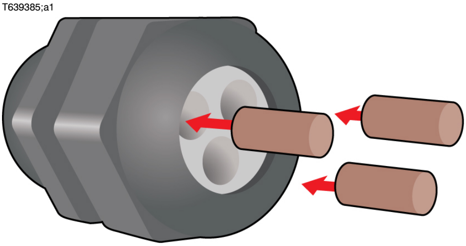
The FLIR A3xx pt series camera comes with two 3/4″ NPT cable glands, each with a three hole gland seal insert. Cables may be between 0.23″ to 0.29″ OD. Up to six cables may be installed. Plugs are required for the insert hole(s) not being used.

T639377;a2



1	Shipping plug
2	Breather valve
3	Shipping plug
4	Ground lug
5	Mounting screw (×6)

T639385;a1



If non-standard cable diameters are used, you may need to locate or fabricate the appropriate insert to fit the desired cable. FLIR Systems does not provide cable gland inserts other than what is supplied with the system.

NOTE: Insert the cables through the cable glands on the enclosure before terminating and connecting them. (In general, the terminated connectors will not fit through the cable gland.) If a terminated cable is required, you can make a clean and singular cut in the gland seal to install the cable into the gland seal.

Proper installation of cable sealing glands and use of appropriate elastomer inserts is critical to long term reliability. Cables enter the camera mount enclosure through liquid-tight compression glands. Be sure to insert the cables through the cable glands on the enclosure before terminating and connecting them (the connectors will not fit through the cable gland). Leave the gland nuts loosened until all cable installation has been completed. Inspect and install gland fittings in the back cover with suitable leak sealant and tighten to ensure water tight fittings. Teflon tape or pipe sealant (i.e. DuPont RectorSeal T™) are suitable for this purpose.

9.7 Removing the back cover

Use a cross-tip screwdriver to loosen the six captive screws and remove the cover, exposing the connections at the back of the camera. There is a grounding wire connected between the case and the back cover

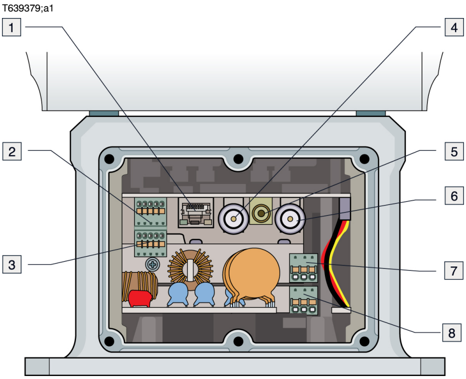


Figure 9.4 1: IP network; 2: Not used; 3: Serial connection for local control; 4: Analog infrared video; 5: Analog video (monitoring output only); 6: Analog visual video; 7: Camera power; 8: Heater power

9.8 Connecting power

The camera itself does not have an on/off switch. Generally the FLIR A3xx pt series camera will be connected to a circuit breaker and the circuit breaker will be used to apply or remove power to the camera. If power is supplied to it, the camera will be in one of two modes: Booting Up or Powered On.

The power cable supplied by the installer must use wires that are sufficient size gauge (16 AWG recommended) for the supply voltage and length of the cable run, to ensure adequate current carrying capacity. Always follow local building codes.

Ensure the camera is properly grounded. Typical to good grounding practices, the camera chassis ground should be provided using the lowest resistance path possible. FLIR Systems requires using a grounding strap anchored to the grounding lug on the back plate of the camera housing and connected to the nearest earth-grounding point.

NOTE: The terminal blocks for power connections will accept a maximum 16 AWG wire size.

9.9 Video connections

The analog video connections on the back of the camera are BNC connectors.

The video cable used should be rated as RG59U or better to ensure a quality video signal.

9.10 Ethernet connection

The cable gland seal is designed for use with Shielded Category 6 Ethernet cable.

9.11 Serial communications overview

The installer must first decide if the serial communications settings will be configured via hardware (DIP switch settings) or software. If the camera has an Ethernet connection, then generally it will be easier (and more convenient in the long run) to make configuration settings via software. Then configuration changes can be made over the network without physically accessing the camera. Also the settings can be saved to a file and backed up or restored as needed.

If the camera is configured via hardware, then configuration changes in the future may require accessing the camera on a tower or pole, dismounting it, and removing the back and so on. If the camera does not have an Ethernet connection, the DIP switches must be used to set the serial communication options.

- The serial communications parameters for the FLIR A3xx pt series camera are set or modified either via hardware DIP switch settings or via software, through a web browser interface. A single DIP switch (SW102-9, Software Override) determines whether the configuration comes from the hardware DIP switches or the software settings.
- The DIP switches are only used to control serial communications parameters. Other settings, related to IP camera functions and so on, must be modified via software (using a web browser).

9.12 Serial connections

For serial communications, it is necessary to set the parameters such as the signalling standard (RS-232 or RS-422), baud rate, number of stop bits, parity and so on. It is also necessary to select the communication protocol used (either Pelco D or Bosch) and the camera address.

The camera supports RS-422 and RS-232 serial communications using common protocols (Pelco D, Bosch).

NOTE: The terminal blocks for serial connections will accept a maximum 20 AWG wire size.

9.13 *Setting configuration dip switches*

The figure below shows the locations of dip switches SW102 and SW103

T639367;a2

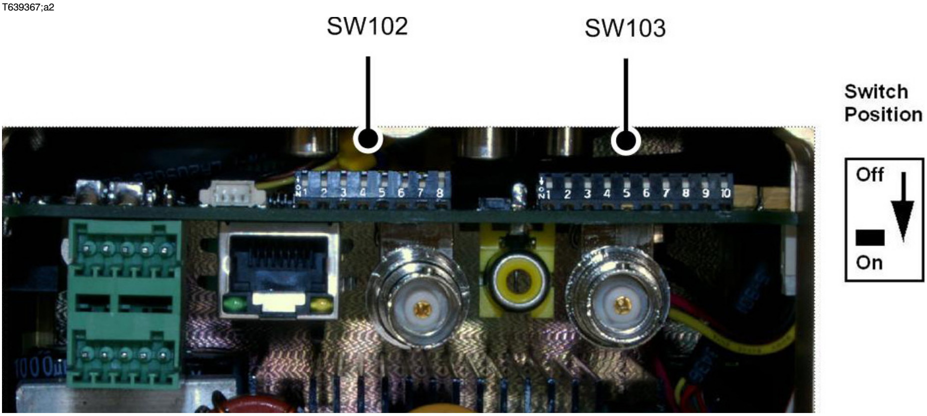


Figure 9.5 FLIR A3xx pt series camera configuration

Pelco Address: This is the address of the system when configured as a Pelco device. The available range of values is from decimal 0 to 255.

T639368;a1

ID	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
0	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
1	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF
2	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF
3	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF
...	...	...	...	...	...	...	...	...
255	ON	ON	ON	ON	ON	ON	ON	ON

Figure 9.6 Dip switch address/ID settings – SW102

Other serial communication parameters: The tables below defines the switch locations, bit numbering and on/off settings.

T639369;a1

	Settings		Description
Baud rate: This is the baud rate of the system user serial port. The available values are 2400, 4800, 9600, 19200 kbaud.	**Bit 1**	**Bit 2**	
	OFF	OFF	2400
	ON	OFF	4800
	OFF	ON	9600
	ON	ON	19200
Camera Control Protocol: This is the communication protocol selected for the system when operating over the serial port. The available protocols are Pelco-D and Bosch.	**Bit 3**	**Bit 4**	
	OFF	OFF	Pelco-D
	ON	OFF	NA
	OFF	ON	Bosch
	ON	ON	NA
Serial Communication Standard: This determines the electrical interface selected for the user serial port. The available settings are RS422 and RS232.	**Bit 5**	**Bit 6**	
	OFF	OFF	NA
	ON	OFF	RS422
	OFF	ON	RS232
	ON	ON	N/A
Not Used	**Bit 7**	**Bit 8**	
	X	X	
	X	X	
	X	X	
	X	X	
Software Override DIP Switch: This setting determines whether the system will use software settings for configuration or if the dip switch settings will override the software settings. Default is Off.	**Bit 9**		
	OFF		Software select
	ON		Hardware select
Not Used	**Bit 10**		
	X		

Figure 9.7 Dip switch address/ID settings – SW103

10 Verifying camera operation (FLIR A3xx f series)

Prior to installing the camera, use a bench test to verify camera operation and configure the camera for the local network. The camera provides analog video and can be controlled through either serial or IP communications.

10.1 Power and analog video

1. Connect the power, video, and serial cables to the camera.
2. Connect the video cable from the camera to a display/monitor and connect the power cable to a power supply. The camera operates on 21–30 VAC or 21–30 VDC. Verify that video is displayed on the monitor.

10.2 Verify IP Communications

As shipped from the factory, the FLIR A3xx f series camera has an IP address of 192.168.250.116 with a netmask of 255.255.255.0.

1. Configure a laptop or PC with another IP address from this network (for example, 192.168.250.)
2. Connect the camera and the laptop to the same Ethernet switch (or back-to-back with an Ethernet crossover cable). In some cases, a straight Ethernet cable can be used, because many PCs have auto detect Ethernet interfaces.
3. Open a web browser, enter http://192.168.250.116 in the address bar, and press Enter. The Web Configurator will start at the Login screen.

T639349;a1

If the Login screen appears, then you have established IP communications with the camera. It is not necessary to log in and use the Web Configuration tool right away. At this time, perform a bench test of the camera using the FLIR Sensor Manager software and the factory configured IP address.

11 Verifying camera operation (FLIR A3xx pt series)

Prior to installing the camera, use a bench test to verify camera operation and configure the camera for the local network. The camera provides analog video and can be controlled through either serial or IP communications providing streaming video over an IP network.

11.1 Power and analog video

1. Connect the power, video, and serial cables to the camera.
2. Connect the video cable from the camera to a display/monitor and connect the power cable to a power supply. The camera operates on 21–30 VAC or 21–30 VDC. Verify that video is displayed on the monitor.
3. Connect the serial cable from the camera to a serial device such as a keyboard, and confirm that the camera is responding to serial commands. Before using serial communications, it may be necessary to configure the serial device interface to operate with the camera. When the camera is turned on, the video temporarily displays system information including the serial number, IP address, Pelco address, Baud rate, and setting of the serial control DIP switch: SW – software control (the default) or HW – hardware.

   - S/N: 1234567
   - IP Addr: 192.168.250.116
   - PelcoD (Addr:1): 9600 SW

11.2 Verify IP communications

As shipped from the factory, the FLIR A3xx pt series camera has an IP address of 192.168.250.116 with a netmask of 255.255.255.0.

1. Configure a laptop or PC with another IP address from this network (for example, 192.168.250. In some cases, a straight Ethernet cable can be used, because many PCs have auto detect Ethernet interfaces.
2. Connect the camera and the laptop to the same Ethernet switch (or back-to-back with an Ethernet crossover cable).
3. Open a web browser, enter http://192.168.250.116 in the address bar, and press Enter.

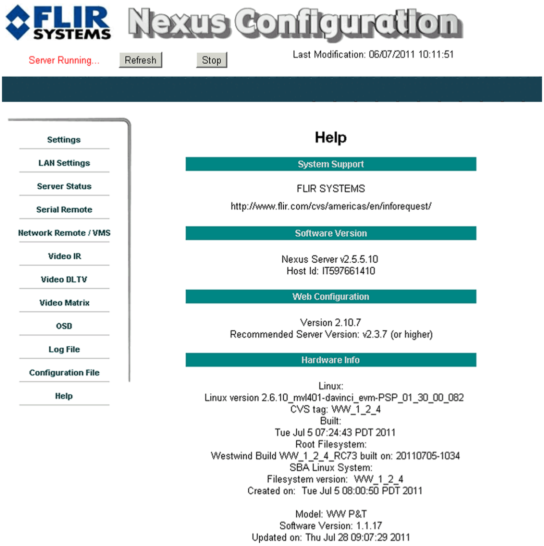
T639362;a1

The Web Configurator will start at the Login screen. If the Login screen appears, then you have established IP communications with the camera. It is not necessary to log in and use the Web Configuration tool right away. At this time, perform a bench test of the camera using the FLIR Sensors Manager software and the factory configured IP address.

11.3 FLIR A3xx pt series configuration

After logging in, the Help screen is displayed. This screen has information about the camera including hardware and software revision numbers, part numbers, and serial numbers. If you need to contact FLIR Systems for support, this information will be useful to the support engineer. Use the menu entries at the left of the screen shown in the figure below to configure the FLIR A3xx pt series series camera.

T639356;a1

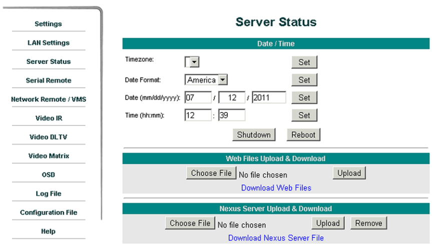


The following paragraphs show the pages for setting serial communication parameters and setting a new IP address for a camera on a local area network.

11.3.1 Set the date and time

1 Click **Server Status**. The screen below will be displayed.

T639354;a1



2 Set the **Timezone** from the pull down menu. Click **Set**.
3 Set the **Date Format** from the pull down menu. Click **Set**.
4 Set the **Date** by typing in the dialog boxes. Click **Set**.
5 Set the **Time** by typing in the dialog boxes. Click **Set**.

11.3.2 Serial remote menu

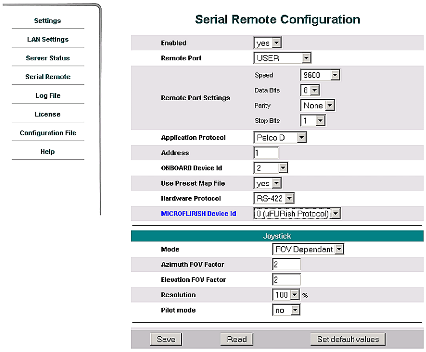
The settings you make in this screen will become active when the software override DIP switch is set to Off (the default) allowing software settings to control the camera.

NOTE: This menu is disabled by default. You need to enable it before changing any settings.

---

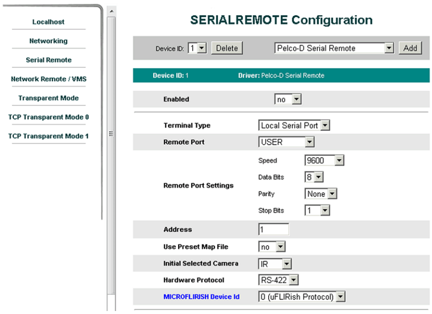
1 Click **Serial Remote**. The screen below will be displayed.

T639353;a1



2 Select the **Protocol** for your serial control configuration. (**Pelco-D Serial Remote** in this example). Select **Device ID: 1** to see the Pelco-D advanced settings. (If you selected Bosch Serial Remote in 2 above, you will select **Device ID: 2** to see the Bosch advanced settings.)

T639348;a1



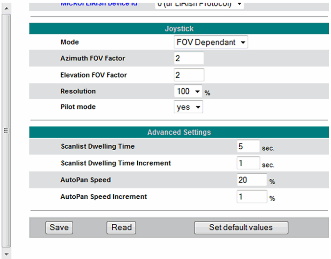
3 Enter the parameters for your specific location.

4 Scroll down to see more advanced settings.

11.3.2.1 Scanlist Serial Control

1 Scroll down until you see the **Advanced Settings** section shown in the screen below.

T639370;a1



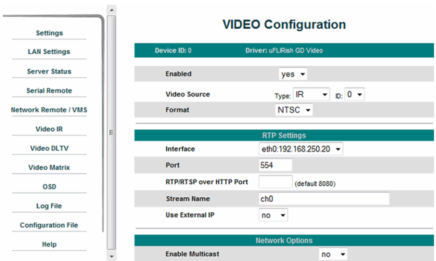
2 Enter the scanning parameters for your specific location.

11.3.3 Digital video configuration—video IR and video DLTV

NOTE: When defining the ports for digital video, streams are setup sequentially; 0, 1, 2, and 3. If a stream is enabled, the server will use the RTP/RTSP over HTTP port parameter to define the port number (if left blank, 8080 is used). A subsequent stream's configuration takes precedence so the same port needs to be defined for all enabled video streams. (But actually you could really only define a non-default port for the last video stream configured.)

1 Click **Video IR**. The screen below will be displayed.

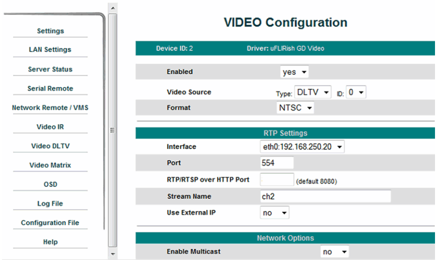
T639373;a1



2 Enter the parameters for your IR video stream. The **IR Stream Name** contains the connection string for the IP video. The default value recognized by FLIR Sensor Manager as ch0 is: rtsp://192.168.250.116/ch0. Enter the appropriate IP video connection string for your installation.

3 Click **Video DLTV**. The screen below will be displayed.

T639372;a1



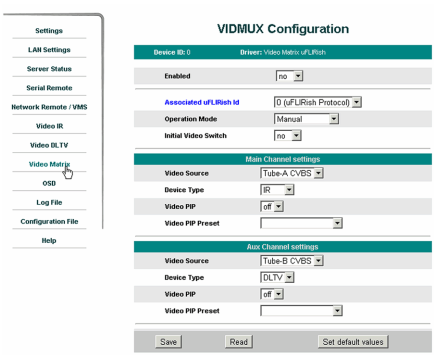
4 Enter the parameters for your visible video stream. The **DLTV Stream Name** contains the connection string for the IP video. The default value recognized by FLIR Sensor Manager as ch2 is: rtsp://192.168.250.116/ch2. Enter the appropriate IP video connection string for your installation.

11.3.4 Analog video configuration—video matrix

Click **Video Matrix**. The screen below will be displayed.

NOTE: This menu is disabled by default. You need to enable it before changing any settings.

T639371;a1



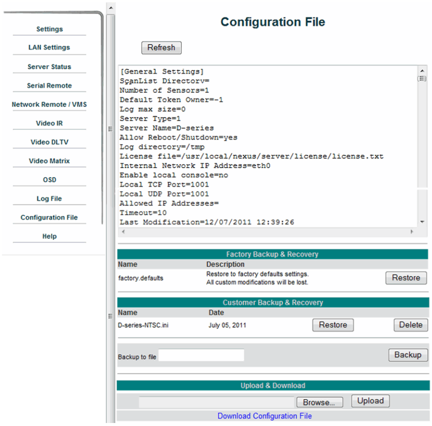
The FLIR A3xx pt series camera provides two analog video ports: Main and Auxiliary.

- You can select the source of each port from this screen.
- Set the **Device type** (set **Device ID**) for each source.
- Set **Picture-In-Picture (PIP)** for each port.

11.3.5 Configuration file

1 Click **Configuration File**. The screen below will be displayed. Shown at the top of the screen is the .ini file in a scrollable window. This can help if you ever need help from a support engineer.

T639350;a1



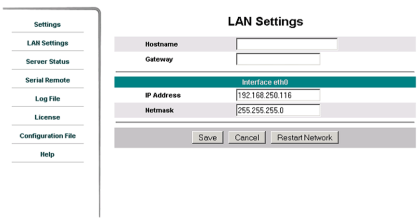
2 Click **Restore** in the **Factory Backup and Restore** section to reconfigure the file to the settings sent from the factory. This file can not be modified or deleted, so it is always available.
3 In the **Customer Backup and Recovery** section, make a backup of your final custom settings.
4 In the **Upload and Download** section, download a copy to a different network location for safe keeping.

11.3.6 LAN settings

As the final step in configuring the camera on the bench, you may want to insert a new IP address appropriate for the local area network receiving the camera. Once you are finished with this process you typically will no longer be able to access the camera from the same PC used to see the default IP address.

1 Click **LAN Settings**. The screen below will be displayed.

T639352;a1



2 Enter the **Hostname**, **Gateway**, **IP Address**, and **Netmask** that are appropriate for the local area network. Then click **Save**. A message will appear indicating the IP address has been changed and the browser will no longer be able to communicate with the camera. You must connect the camera to an appropriate local area network (LAN) and connect to the camera using its new IP address.

12 Cleaning the camera

12.1 Camera housing, cables, and other items

Liquids

Use one of these liquids:

- Warm water
- A weak detergent solution

Equipment

A soft cloth

Procedure

Follow this procedure:

1	Soak the cloth in the liquid.
2	Twist the cloth to remove excess liquid.
3	Clean the part with the cloth.

CAUTION

Do not apply solvents or similar liquids to the camera, the cables, or other items. This can cause damage.

12.2 Infrared lens

Liquids

Use one of these liquids:

- 96% ethyl alcohol (C_2H_5OH).
- DEE (= ‘ether’ = diethylether, $C_4H_{10}O$).
- 50% acetone (= dimethylketone, $(CH_3)_2CO$)) + 50% ethyl alcohol (by volume). This liquid prevents drying marks on the lens.

Equipment

Cotton wool

Procedure

Follow this procedure:

1	Soak the cotton wool in the liquid.
2	Twist the cotton wool to remove excess liquid.
3	Clean the lens one time only and discard the cotton wool.

WARNING

Make sure that you read all applicable MSDS (Material Safety Data Sheets) and warning labels on containers before you use a liquid: the liquids can be dangerous.

CAUTION

- Be careful when you clean the infrared lens. The lens has a delicate anti-reflective coating.
- Do not clean the infrared lens too vigorously. This can damage the anti-reflective coating.

12.3 Infrared detector

General

Even small amounts of dust on the infrared detector can result in major blemishes in the image. To remove any dust from the detector, follow the procedure below.

NOTE

- This section only applies to cameras where removing the lens exposes the infrared detector.
- In some cases the dust cannot be removed by following this procedure: the infrared detector must be cleaned mechanically. This mechanical cleaning must be carried out by an authorized service partner.

CAUTION

In Step 2 below, do not use pressurized air from pneumatic air circuits in a workshop, etc., as this air usually contains oil mist to lubricate pneumatic tools.

Procedure

Follow this procedure:

1	Remove the lens from the camera.
2	Use pressurized air from a compressed air canister to blow off the dust.

13 Technical data

For technical data for this product, please refer to the product catalog and technical datasheets on the User Documentation CD-ROM that comes with the camera.

The product catalog and the datasheets are also available at http://support.flir.com.

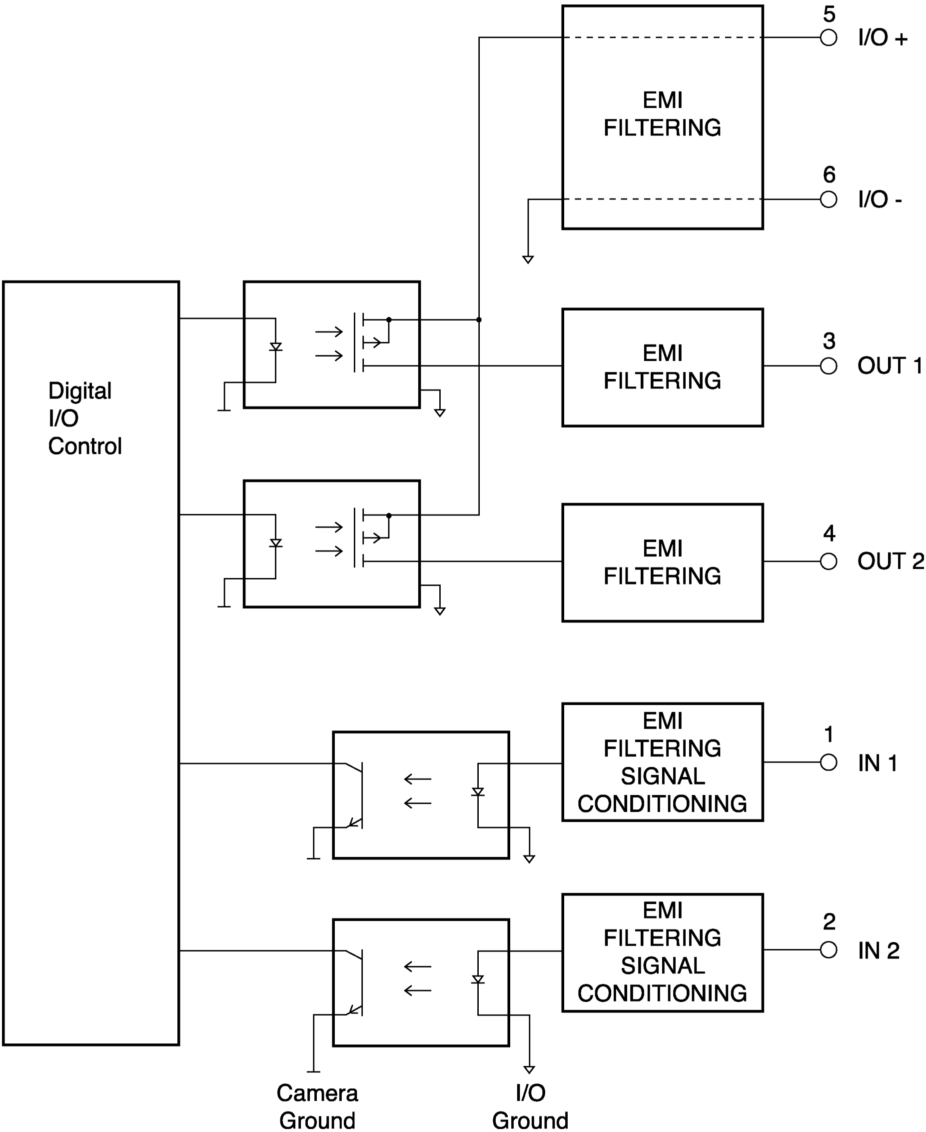
14 Pin configurations and schematics

14.1 Pin configuration for camera I/O connector

Pin	Configuration
1	IN 1
2	IN 2
3	OUT 1
4	OUT 2
5	I/O +
6	I/O –

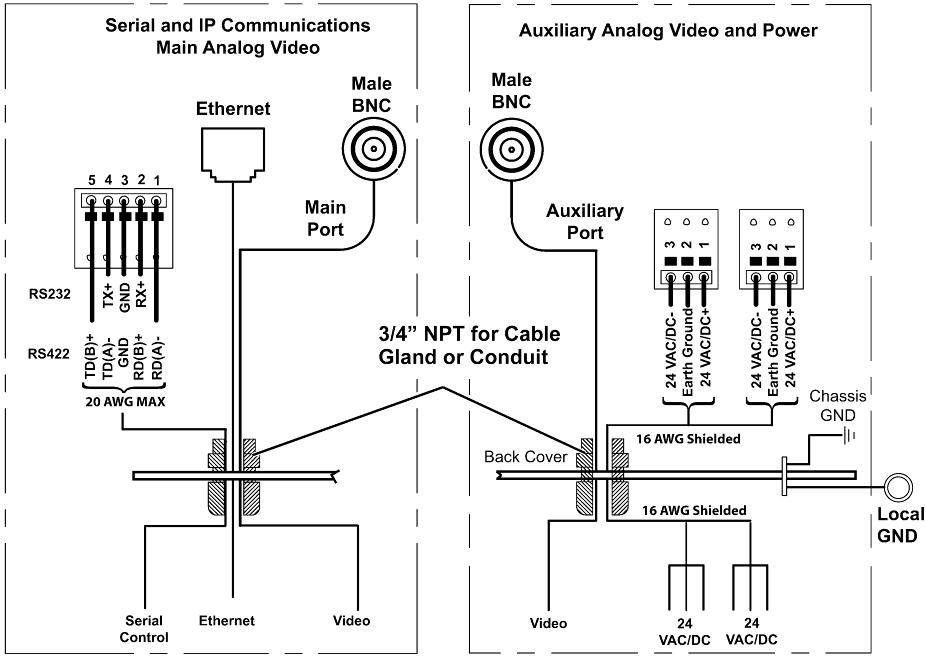
14.2 Schematic overview of the camera unit digital I/O ports

10771603;a1



14.3 Schematic overview of the A3xx pt board

T639498;a1



Gland A Camera End

Gland B Camera End

15 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high-performance infrared imaging systems, and is the world leader in the design, manufacture, and marketing of thermal imaging systems for a wide variety of commercial, industrial, and government applications. Today, FLIR Systems embraces five major companies with outstanding achievements in infrared technology since 1958—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), the three United States companies Indigo Systems, FSI, and Inframetrics, and the French company Cedip. In November 2007, Extech Instruments was acquired by FLIR Systems.

T638608;a1

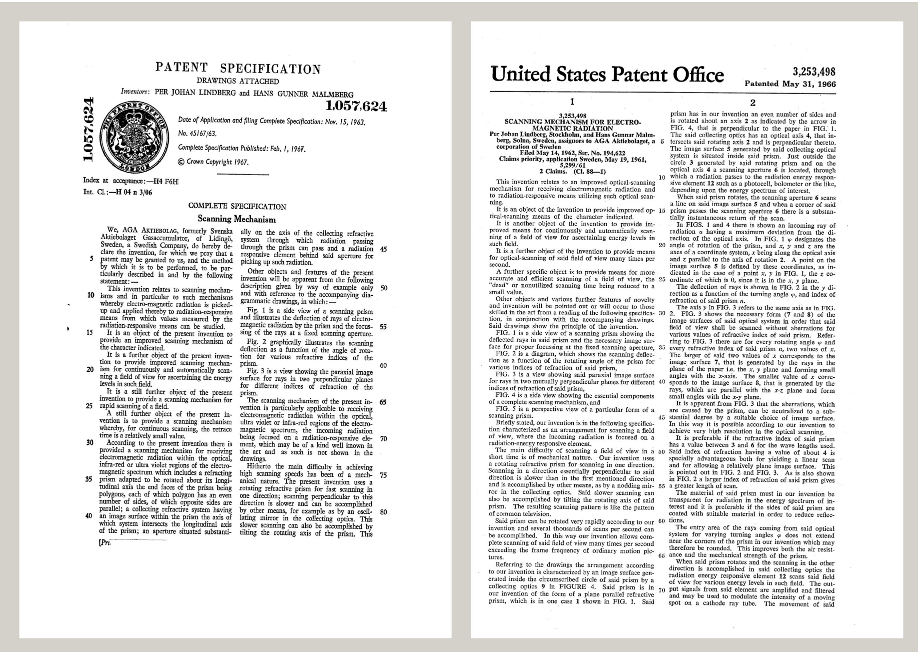


Figure 15.1 Patent documents from the early 1960s

The company has sold more than 200,000 infrared cameras worldwide for applications such as predictive maintenance, R & D, non-destructive testing, process control and automation, and machine vision, among many others.

FLIR Systems has three manufacturing plants in the United States (Portland, OR, Boston, MA, Santa Barbara, CA) and one in Sweden (Stockholm). Since 2007 there is also a manufacturing plant in Tallinn, Estonia. Direct sales offices in Belgium, Brazil,

China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Korea, Sweden, and the USA—together with a worldwide network of agents and distributors—support our international customer base.

FLIR Systems is at the forefront of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, and the first uncooled infrared camera, to mention just two innovations.

10722703;a2

Figure 15.2 LEFT: Thermovision® Model 661 from 1969. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), and the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg/13 lb.) can be seen. **RIGHT:** FLIR i7 from 2009. Weight: 0.34 kg (0.75 lb.), including the battery.

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing, to lenses and system electronics, to final testing and calibration, all production steps are carried out and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

15.1 More than just an infrared camera

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them with the most powerful

camera–software combination. Especially tailored software for predictive maintenance, R & D, and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

15.2 Sharing our knowledge

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, that provides certified training courses. Attending one of the ITC courses will give you a truly hands-on learning experience.

The staff of the ITC are also there to provide you with any application support you may need in putting infrared theory into practice.

15.3 Supporting our customers

FLIR Systems operates a worldwide service network to keep your camera running at all times. If you discover a problem with your camera, local service centers have all the equipment and expertise to solve it within the shortest possible time. Therefore, there is no need to send your camera to the other side of the world or to talk to someone who does not speak your language.

15.4 A few images from our facilities

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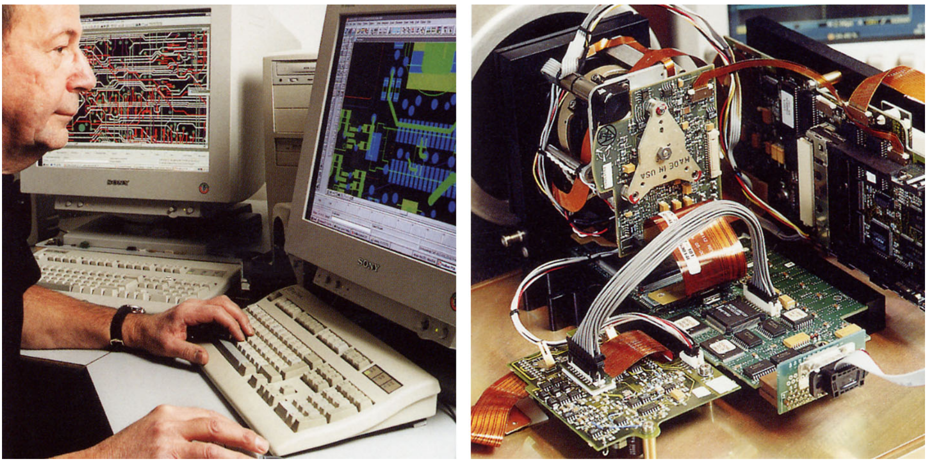

Figure 15.3 **LEFT:** Development of system electronics; **RIGHT:** Testing of an FPA detector

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Figure 15.4 **LEFT:** Diamond turning machine; **RIGHT:** Lens polishing

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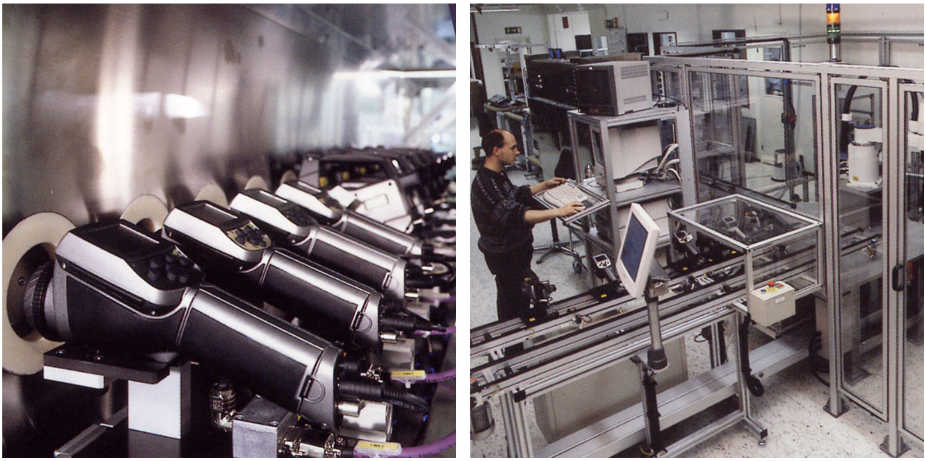


Figure 15.5 **LEFT:** Testing of infrared cameras in the climatic chamber; **RIGHT:** Robot used for camera testing and calibration

16 Glossary

Term or expression	Explanation
absorption (absorption factor)	The amount of radiation absorbed by an object relative to the received radiation. A number between 0 and 1.
atmosphere	The gases between the object being measured and the camera, normally air.
autoadjust	A function making a camera perform an internal image correction.
autopalette	The IR image is shown with an uneven spread of colors, displaying cold objects as well as hot ones at the same time.
blackbody	Totally non-reflective object. All its radiation is due to its own temperature.
blackbody radiator	An IR radiating equipment with blackbody properties used to calibrate IR cameras.
calculated atmospheric transmission	A transmission value computed from the temperature, the relative humidity of air and the distance to the object.
cavity radiator	A bottle shaped radiator with an absorbing inside, viewed through the bottleneck.
color temperature	The temperature for which the color of a blackbody matches a specific color.
conduction	The process that makes heat diffuse into a material.
continuous adjust	A function that adjusts the image. The function works all the time, continuously adjusting brightness and contrast according to the image content.
convection	Convection is a heat transfer mode where a fluid is brought into motion, either by gravity or another force, thereby transferring heat from one place to another.
dual isotherm	An isotherm with two color bands, instead of one.
emissivity (emissivity factor)	The amount of radiation coming from an object, compared to that of a blackbody. A number between 0 and 1.
emittance	Amount of energy emitted from an object per unit of time and area (W/m^2)
environment	Objects and gases that emit radiation towards the object being measured.
estimated atmospheric transmission	A transmission value, supplied by a user, replacing a calculated one

Term or expression	Explanation
external optics	Extra lenses, filters, heat shields etc. that can be put between the camera and the object being measured.
filter	A material transparent only to some of the infrared wavelengths.
FOV	Field of view: The horizontal angle that can be viewed through an IR lens.
FPA	Focal plane array: A type of IR detector.
graybody	An object that emits a fixed fraction of the amount of energy of a blackbody for each wavelength.
IFOV	Instantaneous field of view: A measure of the geometrical resolution of an IR camera.
image correction (internal or external)	A way of compensating for sensitivity differences in various parts of live images and also of stabilizing the camera.
infrared	Non-visible radiation, having a wavelength from about 2–13 μm.
IR	infrared
isotherm	A function highlighting those parts of an image that fall above, below or between one or more temperature intervals.
isothermal cavity	A bottle-shaped radiator with a uniform temperature viewed through the bottleneck.
Laser LocatIR	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
laser pointer	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
level	The center value of the temperature scale, usually expressed as a signal value.
manual adjust	A way to adjust the image by manually changing certain parameters.
NETD	Noise equivalent temperature difference. A measure of the image noise level of an IR camera.
noise	Undesired small disturbance in the infrared image
object parameters	A set of values describing the circumstances under which the measurement of an object was made, and the object itself (such as emissivity, reflected apparent temperature, distance etc.)
object signal	A non-calibrated value related to the amount of radiation received by the camera from the object.

Term or expression	Explanation
palette	The set of colors used to display an IR image.
pixel	Stands for *picture element*. One single spot in an image.
radiance	Amount of energy emitted from an object per unit of time, area and angle ($W/m^2/sr$)
radiant power	Amount of energy emitted from an object per unit of time (W)
radiation	The process by which electromagnetic energy, is emitted by an object or a gas.
radiator	A piece of IR radiating equipment.
range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
reference temperature	A temperature which the ordinary measured values can be compared with.
reflection	The amount of radiation reflected by an object relative to the received radiation. A number between 0 and 1.
relative humidity	Relative humidity represents the ratio between the current water vapour mass in the air and the maximum it may contain in saturation conditions.
saturation color	The areas that contain temperatures outside the present level/span settings are colored with the saturation colors. The saturation colors contain an ‘overflow’ color and an ‘underflow’ color. There is also a third red saturation color that marks everything saturated by the detector indicating that the range should probably be changed.
span	The interval of the temperature scale, usually expressed as a signal value.
spectral (radiant) emittance	Amount of energy emitted from an object per unit of time, area and wavelength ($W/m^2/\mu m$)
temperature difference, or difference of temperature.	A value which is the result of a subtraction between two temperature values.
temperature range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
temperature scale	The way in which an IR image currently is displayed. Expressed as two temperature values limiting the colors.
thermogram	infrared image

Term or expression	Explanation
transmission (or transmittance) factor	Gases and materials can be more or less transparent. Transmission is the amount of IR radiation passing through them. A number between 0 and 1.
transparent isotherm	An isotherm showing a linear spread of colors, instead of covering the highlighted parts of the image.
visual	Refers to the video mode of a IR camera, as opposed to the normal, thermographic mode. When a camera is in video mode it captures ordinary video images, while thermographic images are captured when the camera is in IR mode.

17 Thermographic measurement techniques

17.1 Introduction

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected apparent temperature
- The distance between the object and the camera
- The relative humidity
- Temperature of the atmosphere

17.2 Emissivity

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

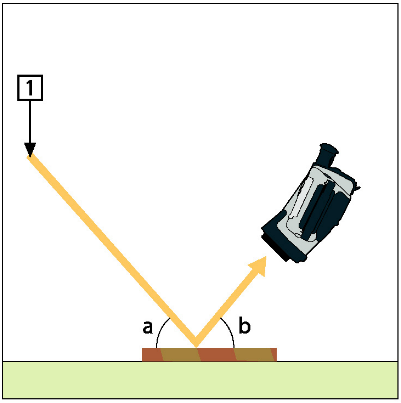
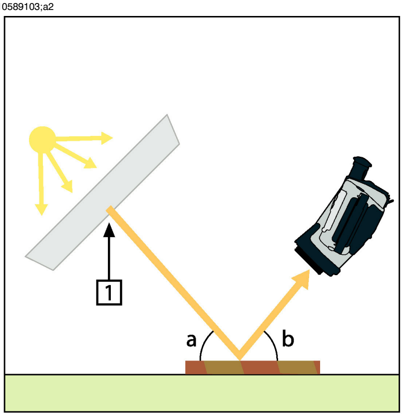
Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

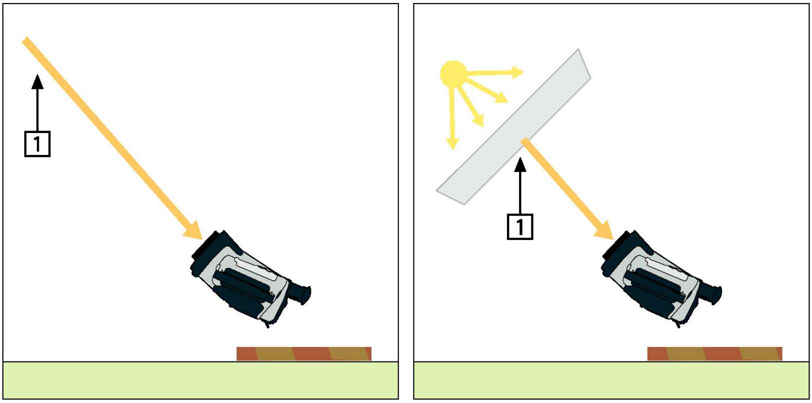
17.2.1 Finding the emissivity of a sample

17.2.1.1 Step 1: Determining reflected apparent temperature

Use one of the following two methods to determine reflected apparent temperature:

17.2.1.1.1 Method 1: Direct method

1	Look for possible reflection sources, considering that the incident angle = reflection angle (a = b). 10588903;a1  **Figure 17.1** 1 = Reflection source
2	If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard. 10589103;a2  **Figure 17.2** 1 = Reflection source

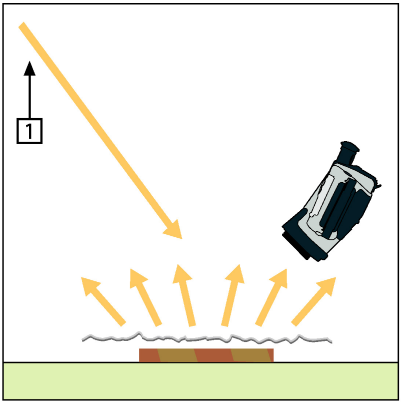
3	Measure the radiation intensity (= apparent temperature) from the reflecting source using the following settings: ■ Emissivity: 1.0 ■ D_{obj}: 0 You can measure the radiation intensity using one of the following two methods: 10589003;a2  **Figure 17.3** 1 = Reflection source

Note: Using a thermocouple to measure reflected apparent temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

17.2.1.1.2 Method 2: Reflector method

1	Crumble up a large piece of aluminum foil.
2	Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size.
3	Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera.
4	Set the emissivity to 1.0.

5	Measure the apparent temperature of the aluminum foil and write it down. 10727003;a2  **Figure 17.4** Measuring the apparent temperature of the aluminum foil

17.2.1.2 Step 2: Determining the emissivity

1	Select a place to put the sample.
2	Determine and set reflected apparent temperature according to the previous procedure.
3	Put a piece of electrical tape with known high emissivity on the sample.
4	Heat the sample at least 20 K above room temperature. Heating must be reasonably even.
5	Focus and auto-adjust the camera, and freeze the image.
6	Adjust **Level** and **Span** for best image brightness and contrast.
7	Set emissivity to that of the tape (usually 0.97).
8	Measure the temperature of the tape using one of the following measurement functions: ▪ **Isotherm** (helps you to determine both the temperature and how evenly you have heated the sample) ▪ **Spot** (simpler) ▪ **Box Avg** (good for surfaces with varying emissivity).
9	Write down the temperature.
10	Move your measurement function to the sample surface.
11	Change the emissivity setting until you read the same temperature as your previous measurement.
12	Write down the emissivity.

Note:

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

17.3 Reflected apparent temperature

This parameter is used to compensate for the radiation reflected in the object. If the emissivity is low and the object temperature relatively far from that of the reflected it will be important to set and compensate for the reflected apparent temperature correctly.

17.4 Distance

The distance is the distance between the object and the front lens of the camera. This parameter is used to compensate for the following two facts:

- That radiation from the target is absorbed by the athmosphere between the object and the camera.
- That radiation from the atmosphere itself is detected by the camera.

17.5 Relative humidity

The camera can also compensate for the fact that the transmittance is also dependent on the relative humidity of the atmosphere. To do this set the relative humidity to the correct value. For short distances and normal humidity the relative humidity can normally be left at a default value of 50%.

17.6 Other parameters

In addition, some cameras and analysis programs from FLIR Systems allow you to compensate for the following parameters:

- Atmospheric temperature – *i.e.* the temperature of the atmosphere between the camera and the target
- External optics temperature – *i.e.* the temperature of any external lenses or windows used in front of the camera
- External optics transmittance – *i.e.* the transmission of any external lenses or windows used in front of the camera

18 History of infrared technology

Before the year 1800, the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply ‘the infrared’ as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

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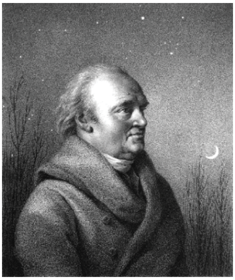

Figure 18.1 Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun’s image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun’s heat, while others passed so much heat that he risked eye damage after only a few seconds’ observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton’s prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun’s rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel,

however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

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Figure 18.2 Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the 'infrared wavelengths'.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the 'thermometrical spectrum'. The radiation itself he sometimes referred to as 'dark heat', or simply 'the invisible rays'. Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term 'infrared'. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel's use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930's.

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Figure 18.3 Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel's own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called 'heat-picture' became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a 'thermograph'.

10399003;a2

Figure 18.4 Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of -196 °C (-320.8 °F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common ‘thermos bottle’, used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world ‘discovered’ the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and ‘flying torpedo’ guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally ‘see in the dark’. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer’s position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active’ (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing ‘passive’ (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950’s, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

19 Theory of thermography

19.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

19.2 The electromagnetic spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

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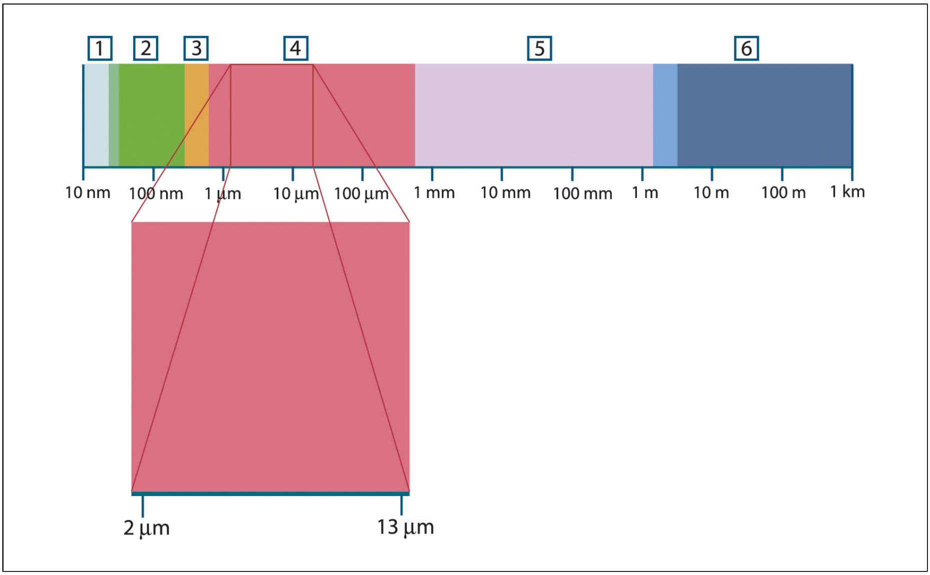

Figure 19.1 The electromagnetic spectrum. **1:** X-ray; **2:** UV; **3:** Visible; **4:** IR; **5:** Microwaves; **6:** Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100

µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

19.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

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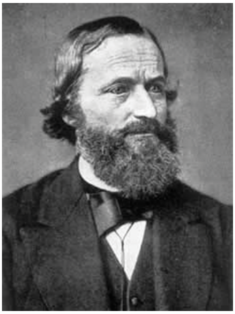

Figure 19.2 Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525°C (977°F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

19.3.1 Planck's law

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Figure 19.3 Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6} [Watt\,/\,m^2, \mu m]$$

where:

$W_{\lambda b}$	Blackbody spectral radiant emittance at wavelength λ.
c	Velocity of light = 3 × 10^8 m/s
h	Planck's constant = 6.6 × 10^{-34} Joule sec.
k	Boltzmann's constant = 1.4 × 10^{-23} Joule/K.
T	Absolute temperature (K) of a blackbody.
λ	Wavelength (μm).

➲ The factor 10^{-6} is used since spectral emittance in the curves is expressed in Watt/m^2, µm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at $\lambda = 0$, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

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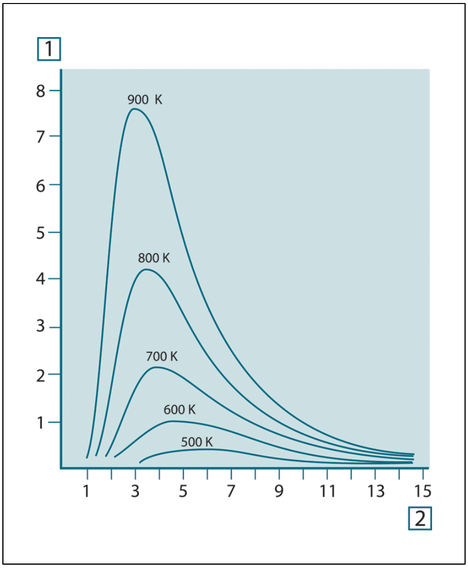

Figure 19.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. **1:** Spectral radiant emittance (W/cm^2 × 10^3(µm)); **2:** Wavelength (µm)

19.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{max}. A good approximation of the value of λ_{max} for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T

µm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 µm.

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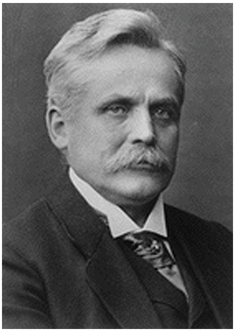

Figure 19.5 Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

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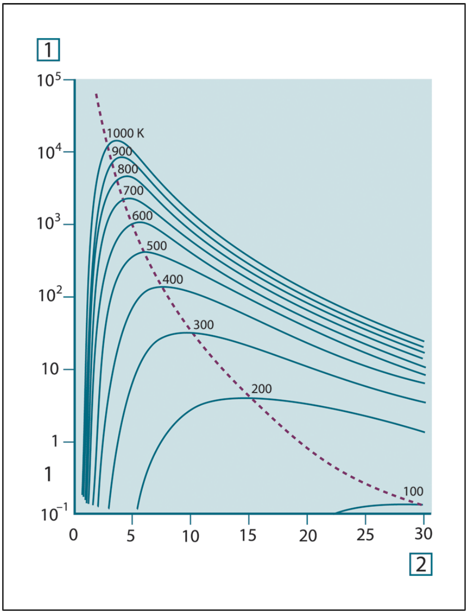

Figure 19.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. **1:** Spectral radiant emittance (W/cm² (μm)); **2:** Wavelength (μm).

19.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$, we obtain the total radiant emittance (W_b) of a blackbody:

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval $\lambda = 0$ to λ_{max} is only 25% of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

10399303;a1

Figure 19.7 Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m^2, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

19.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ= the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\alpha_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity ε_λ= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1
- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

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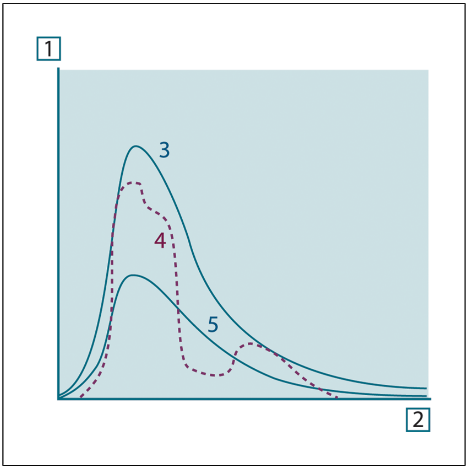

Figure 19.8 Spectral radiant emittance of three types of radiators. **1:** Spectral radiant emittance; **2:** Wavelength; **3:** Blackbody; **4:** Selective radiator; **5:** Graybody.

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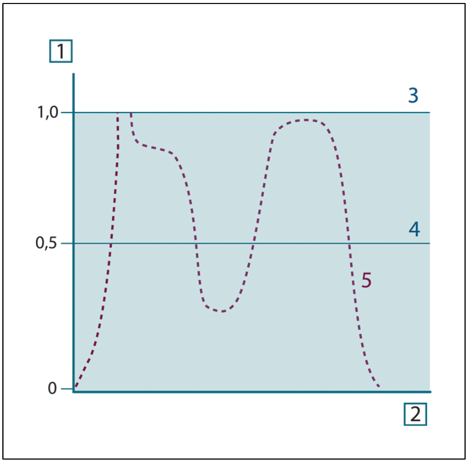

Figure 19.9 Spectral emissivity of three types of radiators. **1:** Spectral emissivity; **2:** Wavelength; **3:** Blackbody; **4:** Graybody; **5:** Selective radiator.

19.4 Infrared semi-transparent materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but

some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

20 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

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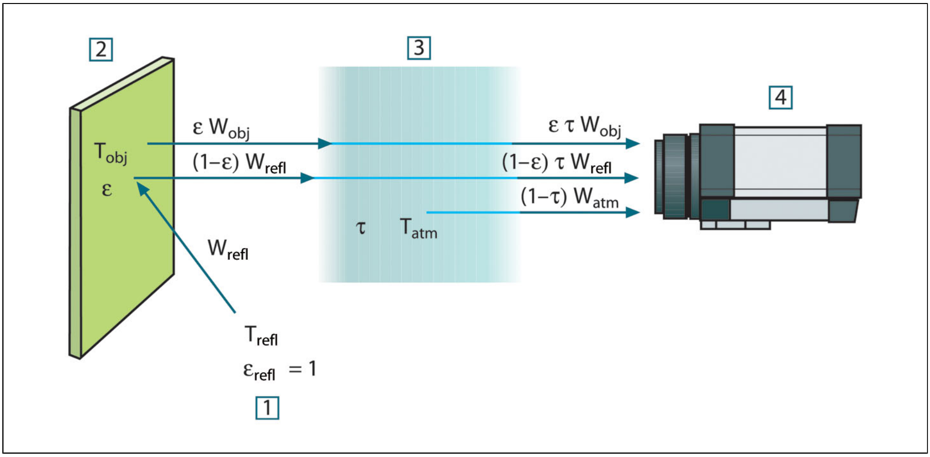

Figure 20.1 A schematic representation of the general thermographic measurement situation.**1:** Surroundings; **2:** Object; **3:** Atmosphere; **4:** Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be εW_{source}.

We are now ready to write the three collected radiation power terms:

1 – Emission from the object = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.

2 – Reflected emission from ambient sources = $(1 – \varepsilon)\tau W_{refl}$, where $(1 – \varepsilon)$ is the reflectance of the object. The ambient sources have the temperature T_{refl}.

It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)

3 – Emission from the atmosphere = $(1 – \tau)\tau W_{atm}$, where $(1 – \tau)$ is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1-\varepsilon)\tau U_{refl} + (1-\tau)U_{atm}$$

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

Figure 20.2 Voltages

U_{obj}	Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
U_{tot}	Measured camera output voltage for the actual case.
U_{refl}	Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
U_{atm}	Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- T_{atm}
- object distance (D_{obj})
- the (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl}, and
- the temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- τ = 0.88
- T_{refl} = +20°C (+68°F)
- T_{atm} = +20°C (+68°F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the ‘disturbing’ radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure U_{tot} = 4.5 volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in U_{obj} = 4.5 / 0.75 / 0.92 – 0.5 = 6.0. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

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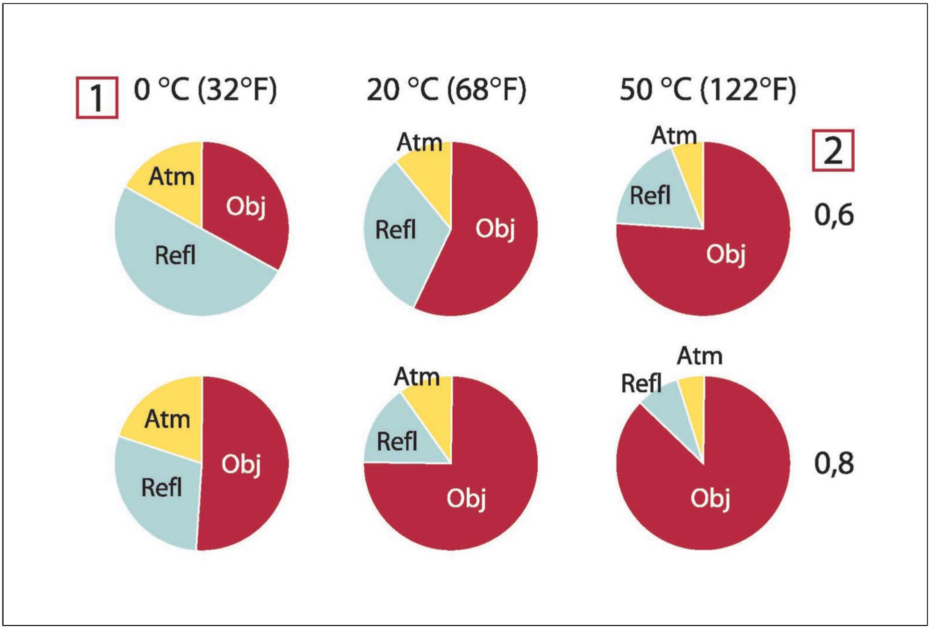

Figure 20.3 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: τ = 0.88; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

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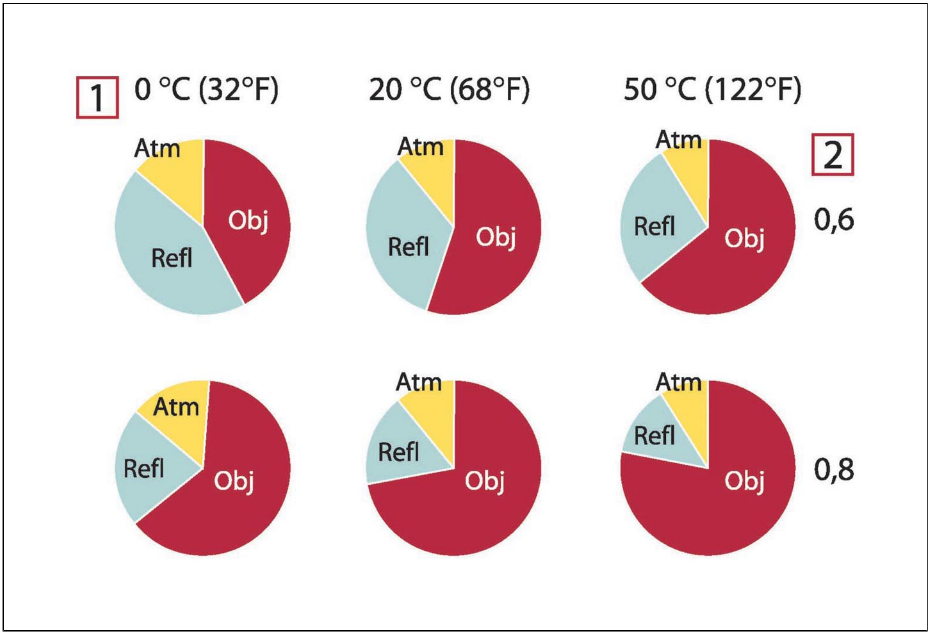

Figure 20.4 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

21 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

21.1 References

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3	Madding, R. P.: *Thermographic Instruments and systems*. Madison, Wisconsin: University of Wisconsin – Extension, Department of Engineering and Applied Science.
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9	Öhman, Claes: *Emittansmätningar med AGEMA E-Box*. Teknisk rapport, AGEMA 1999. (Emittance measurements using AGEMA E-Box. Technical report, AGEMA 1999.)
10	Matteï, S., Tang-Kwor, E: *Emissivity measurements for Nextel Velvet coating 811-21 between –36°C AND 82°C.*
11	Lohrengel & Todtenhaupt (1996)
12	ITC Technical publication 32.
13	ITC Technical publication 29.

21.2 Important note about the emissivity tables

The type of camera that has been used when compiling the emissivity data is specified in column 4. The values should be regarded as recommendations only and used with caution.

21.3 Tables

Figure 21.1 **1:** Material; **2:** Specification; **3:** Temperature in °C; **4:** Spectrum (**T:** Total spectrum; **SW:** 2–5 µm; **LW:** 8–14 µm, **LLW:** 6.5–20 µm); **5:** Emissivity: **6:** Reference to literature source above

1	2	3	4	5	6
3M type 35	Vinyl electrical tape (several colors)	< 80	LW	Ca. 0.96	13
3M type 88	Black vinyl electrical tape	< 105	LW	Ca. 0.96	13
3M type 88	Black vinyl electrical tape	< 105	MW	< 0.96	13
3M type Super 33+	Black vinyl electrical tape	< 80	LW	Ca. 0.96	13
Aluminum	anodized, black, dull	70	LW	0.95	9
Aluminum	anodized, black, dull	70	SW	0.67	9
Aluminum	anodized, light gray, dull	70	LW	0.97	9
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	dipped in HNO_3, plate	100	T	0.05	4
Aluminum	foil	27	3 µm	0.09	3
Aluminum	foil	27	10 µm	0.04	3
Aluminum	oxidized, strongly	50–500	T	0.2–0.3	1
Aluminum	polished	50–100	T	0.04–0.06	1
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	polished plate	100	T	0.05	4

1	2	3	4	5	6
Aluminum	roughened	27	3 μm	0.28	3
Aluminum	roughened	27	10 μm	0.18	3
Aluminum	rough surface	20–50	T	0.06–0.07	1
Aluminum	sheet, 4 samples differently scratched	70	LW	0.03–0.06	9
Aluminum	sheet, 4 samples differently scratched	70	SW	0.05–0.08	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83–0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1
Aluminum oxide	pure, powder (alumina)		T	0.16	1
Asbestos	board	20	T	0.96	1
Asbestos	fabric		T	0.78	1
Asbestos	floor tile	35	SW	0.94	7
Asbestos	paper	40–400	T	0.93–0.95	1
Asbestos	powder		T	0.40–0.60	1
Asbestos	slate	20	T	0.96	1
Asphalt paving		4	LLW	0.967	8
Brass	dull, tarnished	20–350	T	0.22	1
Brass	oxidized	70	SW	0.04–0.09	9
Brass	oxidized	70	LW	0.03–0.07	9
Brass	oxidized	100	T	0.61	2
Brass	oxidized at 600°C	200–600	T	0.59–0.61	1
Brass	polished	200	T	0.03	1
Brass	polished, highly	100	T	0.03	2

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1	2	3	4	5	6
Brass	rubbed with 80-grit emery	20	T	0.20	2
Brass	sheet, rolled	20	T	0.06	1
Brass	sheet, worked with emery	20	T	0.2	1
Brick	alumina	17	SW	0.68	5
Brick	common	17	SW	0.86–0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	fireclay	20	T	0.85	1
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88–0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000–1300	T	0.38	1
Brick	refractory, strongly radiating	500–1000	T	0.8–0.9	1
Brick	refractory, weakly radiating	500–1000	T	0.65–0.75	1
Brick	silica, 95% SiO_2	1230	T	0.66	1
Brick	sillimanite, 33% SiO_2, 64% Al_2O_3	1500	T	0.29	1

1	2	3	4	5	6
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50–150	T	0.55	1
Bronze	powder		T	0.76–0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1
Carbon	graphite, filed surface	20	T	0.98	2
Carbon	graphite powder		T	0.97	1
Carbon	lampblack	20–400	T	0.95–0.97	1
Chipboard	untreated	20	SW	0.90	6
Chromium	polished	50	T	0.10	1
Chromium	polished	500–1000	T	0.28–0.38	1
Clay	fired	70	T	0.91	1
Cloth	black	20	T	0.98	1
Concrete		20	T	0.92	2
Concrete	dry	36	SW	0.95	7
Concrete	rough	17	SW	0.97	5
Concrete	walkway	5	LLW	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	–34	T	0.006	4
Copper	molten	1100–1300	T	0.13–0.15	1
Copper	oxidized	50	T	0.6–0.7	1
Copper	oxidized, black	27	T	0.78	4

1	2	3	4	5	6
Copper	oxidized, heavily	20	T	0.78	2
Copper	oxidized to blackness		T	0.88	1
Copper	polished	50–100	T	0.02	1
Copper	polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	scraped	27	T	0.07	4
Copper dioxide	powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1
Ebonite			T	0.89	1
Emery	coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	lacquer	20	T	0.85–0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	masonite	70	LW	0.88	9
Fiber board	masonite	70	SW	0.75	9
Fiber board	particle board	70	LW	0.89	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	porous, untreated	20	SW	0.85	6
Gold	polished	130	T	0.018	1
Gold	polished, carefully	200–600	T	0.02–0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	polished	20	LLW	0.849	8
Granite	rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	LW	0.77–0.87	9

1	2	3	4	5	6
Granite	rough, 4 different samples	70	SW	0.95–0.97	9
Gypsum		20	T	0.8–0.9	1
Ice: See Water					
Iron, cast	casting	50	T	0.81	1
Iron, cast	ingots	1000	T	0.95	1
Iron, cast	liquid	1300	T	0.28	1
Iron, cast	machined	800–1000	T	0.60–0.70	1
Iron, cast	oxidized	38	T	0.63	4
Iron, cast	oxidized	100	T	0.64	2
Iron, cast	oxidized	260	T	0.66	4
Iron, cast	oxidized	538	T	0.76	4
Iron, cast	oxidized at 600°C	200–600	T	0.64–0.78	1
Iron, cast	polished	38	T	0.21	4
Iron, cast	polished	40	T	0.21	2
Iron, cast	polished	200	T	0.21	1
Iron, cast	unworked	900–1100	T	0.87–0.95	1
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	covered with red rust	20	T	0.61–0.85	1
Iron and steel	electrolytic	22	T	0.05	4
Iron and steel	electrolytic	100	T	0.05	4
Iron and steel	electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175–225	T	0.05–0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950–1100	T	0.55–0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2

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1	2	3	4	5	6
Iron and steel	hot rolled	20	T	0.77	1
Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	oxidized	100	T	0.74	1
Iron and steel	oxidized	100	T	0.74	4
Iron and steel	oxidized	125–525	T	0.78–0.82	1
Iron and steel	oxidized	200	T	0.79	2
Iron and steel	oxidized	1227	T	0.89	4
Iron and steel	oxidized	200–600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	polished	100	T	0.07	2
Iron and steel	polished	400–1000	T	0.14–0.38	1
Iron and steel	polished sheet	750–1050	T	0.52–0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rough, plane surface	50	T	0.95–0.98	1
Iron and steel	rusted, heavily	17	SW	0.96	5
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	shiny oxide layer, sheet,	20	T	0.82	1
Iron and steel	wrought, carefully polished	40–250	T	0.28	1
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1

1	2	3	4	5	6
Iron tinned	sheet	24	T	0.064	4
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	LW	Ca. 0.96	12
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	MW	Ca. 0.97	12
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92–0.94	9
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50–0.53	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	bakelite	80	T	0.83	1
Lacquer	black, dull	40–100	T	0.96–0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1
Lacquer	heat–resistant	100	T	0.92	1
Lacquer	white	40–100	T	0.8–0.95	1
Lacquer	white	100	T	0.92	2
Lead	oxidized, gray	20	T	0.28	1
Lead	oxidized, gray	22	T	0.28	4
Lead	oxidized at 200°C	200	T	0.63	1
Lead	shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1
Leather	tanned		T	0.75–0.80	1
Lime			T	0.3–0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4

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1	2	3	4	5	6
Magnesium		538	T	0.18	4
Magnesium	polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		600–1000	T	0.08–0.13	1
Molybdenum		1500–2200	T	0.19–0.26	1
Molybdenum	filament	700–2500	T	0.1–0.3	1
Mortar		17	SW	0.87	5
Mortar	dry	36	SW	0.94	7
Nextel Velvet 811-21 Black	Flat black	–60–150	LW	> 0.97	10 and 11
Nichrome	rolled	700	T	0.25	1
Nichrome	sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500–1000	T	0.71–0.79	1
Nichrome	wire, oxidized	50–500	T	0.95–0.98	1
Nickel	bright matte	122	T	0.041	4
Nickel	commercially pure, polished	100	T	0.045	1
Nickel	commercially pure, polished	200–400	T	0.07–0.09	1
Nickel	electrolytic	22	T	0.04	4
Nickel	electrolytic	38	T	0.06	4
Nickel	electrolytic	260	T	0.07	4
Nickel	electrolytic	538	T	0.10	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	electroplated on iron, polished	22	T	0.045	4
Nickel	electroplated on iron, unpolished	20	T	0.11–0.40	1

1	2	3	4	5	6
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	oxidized	200	T	0.37	2
Nickel	oxidized	227	T	0.37	4
Nickel	oxidized	1227	T	0.85	4
Nickel	oxidized at 600°C	200–600	T	0.37–0.48	1
Nickel	polished	122	T	0.045	4
Nickel	wire	200–1000	T	0.1–0.2	1
Nickel oxide		500–650	T	0.52–0.59	1
Nickel oxide		1000–1250	T	0.75–0.86	1
Oil, lubricating	0.025 mm film	20	T	0.27	2
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2
Paint	8 different colors and qualities	70	LW	0.92–0.94	9
Paint	8 different colors and qualities	70	SW	0.88–0.96	9
Paint	Aluminum, various ages	50–100	T	0.27–0.67	1
Paint	cadmium yellow		T	0.28–0.33	1
Paint	chrome green		T	0.65–0.70	1
Paint	cobalt blue		T	0.7–0.8	1
Paint	oil	17	SW	0.87	5
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92–0.96	1

1	2	3	4	5	6
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	LW	0.92–0.94	9
Paper	4 different colors	70	SW	0.68–0.74	9
Paper	black		T	0.90	1
Paper	black, dull		T	0.94	1
Paper	black, dull	70	LW	0.89	9
Paper	black, dull	70	SW	0.86	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	green		T	0.85	1
Paper	red		T	0.76	1
Paper	white	20	T	0.7–0.9	1
Paper	white, 3 different glosses	70	LW	0.88–0.90	9
Paper	white, 3 different glosses	70	SW	0.76–0.78	9
Paper	white bond	20	T	0.93	2
Paper	yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9

1	2	3	4	5	6
Plastic	polyurethane isolation board	70	LW	0.55	9
Plastic	polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Plastic	PVC, plastic floor, dull, structured	70	SW	0.94	9
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		100	T	0.05	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum		1000–1500	T	0.14–0.18	1
Platinum		1094	T	0.18	4
Platinum	pure, polished	200–600	T	0.05–0.10	1
Platinum	ribbon	900–1100	T	0.12–0.17	1
Platinum	wire	50–200	T	0.06–0.07	1
Platinum	wire	500–1000	T	0.10–0.16	1
Platinum	wire	1400	T	0.18	1
Porcelain	glazed	20	T	0.92	1
Porcelain	white, shiny		T	0.70–0.75	1
Rubber	hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	polished	19	LLW	0.909	8
Sandstone	rough	19	LLW	0.935	8
Silver	polished	100	T	0.03	2
Silver	pure, polished	200–600	T	0.02–0.03	1

1	2	3	4	5	6
Skin	human	32	T	0.98	2
Slag	boiler	0–100	T	0.97–0.93	1
Slag	boiler	200–500	T	0.89–0.78	1
Slag	boiler	600–1200	T	0.76–0.70	1
Slag	boiler	1400–1800	T	0.69–0.67	1
Snow: See Water					
Soil	dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2
Stainless steel	alloy, 8% Ni, 18% Cr	500	T	0.35	1
Stainless steel	rolled	700	T	0.45	1
Stainless steel	sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, polished	70	SW	0.18	9
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxidized at 800°C	60	T	0.85	2
Stucco	rough, lime	10–90	T	0.91	1
Styrofoam	insulation	37	SW	0.60	7
Tar			T	0.79–0.84	1
Tar	paper	20	T	0.91–0.93	1
Tile	glazed	17	SW	0.94	5
Tin	burnished	20–50	T	0.04–0.06	1
Tin	tin–plated sheet iron	100	T	0.07	2

1	2	3	4	5	6
Titanium	oxidized at 540°C	200	T	0.40	1
Titanium	oxidized at 540°C	500	T	0.50	1
Titanium	oxidized at 540°C	1000	T	0.60	1
Titanium	polished	200	T	0.15	1
Titanium	polished	500	T	0.20	1
Titanium	polished	1000	T	0.36	1
Tungsten		200	T	0.05	1
Tungsten		600–1000	T	0.1–0.16	1
Tungsten		1500–2200	T	0.24–0.31	1
Tungsten	filament	3300	T	0.39	1
Varnish	flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	LW	0.90–0.93	9
Varnish	on oak parquet floor	70	SW	0.90	9
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	distilled	20	T	0.96	2
Water	frost crystals	–10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	–10	T	0.96	2
Water	ice, smooth	0	T	0.97	1
Water	layer >0.1 mm thick	0–100	T	0.95–0.98	1
Water	snow		T	0.8	1
Water	snow	–10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	ground		T	0.5–0.7	1

1	2	3	4	5	6
Wood	pine, 4 different samples	70	LW	0.81–0.89	9
Wood	pine, 4 different samples	70	SW	0.67–0.75	9
Wood	planed	20	T	0.8–0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	LW	0.88	9
Wood	planed oak	70	SW	0.77	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreat-ed	20	SW	0.83	6
Wood	white, damp	20	T	0.7–0.8	1
Zinc	oxidized at 400°C	400	T	0.11	1
Zinc	oxidized surface	1000–1200	T	0.50–0.60	1
Zinc	polished	200–300	T	0.04–0.05	1
Zinc	sheet	50	T	0.20	1

A note on the technical production of this publication

This publication was produced using XML—the *eXtensible Markup Language*. For more information about XML, please visit http://www.w3.org/XML/

A note on the typeface used in this publication

This publication was typeset using Swiss 721, which is Bitstream's pan-European version of the Helvetica™ typeface. Helvetica™ was designed by Max Miedinger (1910–1980).

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